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(54) Electromechanical grating display system with spatially separated light beams

(57) A display system, that includes a light source for providing illumination; a linear array of electromechanical grating devices of at least two individually operable devices receiving the illumination wherein a grating period is oriented at a predetermined angle with respect to an axis of the linear array wherein the angle is large enough to separate diffracted light beams prior to a lens system for projecting light onto a screen; an obstructing element for blocking a discrete number of diffracted light beams from reaching the screen; a scanning element for moving non-obstructed diffracted light beams on the screen; and a controller for providing a data stream to the individually operable devices.

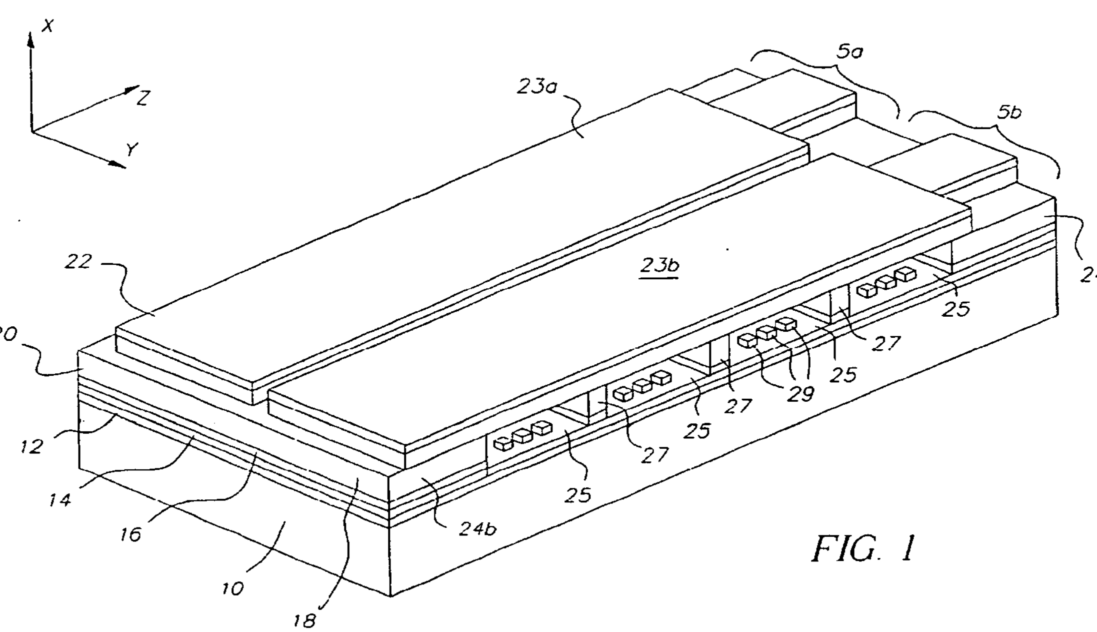

FIG. 1

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Description

[0001] This invention relates to a display system with a linear array of electromechanical grating modulators that is scanned in order to generate a two-dimensional image. More particularly, the invention relates to an electromechanical grating display system that has spatially separated diffracted light beams throughout the system.

[0002] Electromechanical spatial light modulators with a variety of designs have been used in applications such as display, optical processing, printing, optical data storage and spectroscopy. These modulators produce spatial variations in the phase and/or amplitude of an incident light beam using arrays of individually addressable devices.

[0003] Spatial phase modulation of an incident beam can be accomplished by arrays of individually addressable deformable mirrors. Such devices can be made by suspending a deformable reflective membrane over a grid of supports, as described US Patent 4,441,791 issued April 10, 1984 to Hornbeck. However, because of the membrane and support structure, these particular deformable mirrors are very inefficient. More efficient deformable mirror designs are disclosed in US Patent 5,170,283 issued December 8, 1992 to O'Brien et al., and in US Patent 5,844,711 issued December 1, 1998 to Long, Jr.

[0004] Another class of electromechanical spatial light modulators has devices with a periodic sequence of reflective elements that form electromechanical phase gratings. In such devices, the incident light beam is selectively reflected or diffracted into a number of light beams of discrete orders. Depending on the application, one or more of these diffracted light beams may be collected and used by the optical system. For many applications, electromechanical phase gratings are preferable to deformable mirrors. Electromechanical phase gratings can be formed in metallized elastomer gels; see US Patent 4,626,920 issued December 2, 1986 to Glenn, and US Patent 4,857,978 issued August 15, 1989 to Goldburt et al. The electrodes below the elastomer are patterned so that the application of a voltage deforms the elastomer producing a nearly sinusoidal phase grating. These types of devices have been successfully used in color projection displays; see *Metallized viscoelastic control layers for light-valve projection displays,* by Brinker et al., **Displays** 16, 1994, pp. 13-20, and *Full-colour diffraction-based optical system for light-valve projection displays,* by Roder et al., **Displays** 16, 1995, pp. 27-34.

[0005] An electromechanical phase grating with a much faster response time can be made of suspended micromechanical ribbon elements, as described in US Patent 5,311,360 issued May 10, 1994 to Bloom et al. This device, also known as a grating light valve (GLV), can be fabricated with CMOS-like processes on silicon. Improvements in the device were later described by Bloom et al. that included: 1) patterned raised areas beneath the ribbons to minimize contact area to obviate stiction between the ribbons and the substrate, and 2) an alternative device design in which the spacing between ribbons was decreased and alternate ribbons were actuated to produce good contrast; see US Patent 5,459,610 issued October 17, 1995. Bloom et al. also presented a method for fabricating the device; see US Patent 5,677,783 issued October 14, 1997. Additional improvements in the design and fabrication of the GLV were described in US Patent 5,841,579 issued November 24, 1998 to Bloom et al., and in US Patent 5,661,592 issued August 26, 1997 to Bornstein et al.

[0006] For display or printing, linear arrays of GLV devices can be used with a scanning Schlieren optical system as described in US Patent 5,982,553 issued November 9, 1999 to Bloom et al. Alternatively, an interferometric optical system can be used to display an image as disclosed in US Patent 6,088,102 issued July 11, 2000 to Manhart. In the scanning Schlieren display system of Bloom et al. '553, the plane of diffraction, which contains the diffracted light beams, is parallel to the axis of the linear GLV array because the grating period is parallel to the axis. This increases the cost and complexity of the display system. Specifically, efficient collection of the primary diffracted light beams requires at least one dimension of the optical elements to be significantly larger than the extent of the linear GLV array. Furthermore, the diffracted and reflected light beams overlap spatially throughout most of the optical system. Separation of diffracted light from reflected light is accomplished in close proximity to a Fourier plane of the Schlieren optical system. However, the Fourier plane is usually also the preferred location of a scanning mirror for producing a two-dimensional image.

[0007] Recently, a linear array of electromechanical conformal grating devices was disclosed by Kowarz in EPO Application no. 01200128.5 filed January 15, 2001. For this type of device, it is preferable to have the grating period perpendicular to the axis of the linear array. The diffracted light beams are then spatially separated throughout most of the optical system. In EPO Application No. 01200128.5, it was mentioned that a simplified display system is possible to use with a new device. However, no specific description of the display system was given. There is a need therefore for a scanning display system that utilizes a linear array of electromechanical conformal grating devices. Furthermore, there is a need for a system that is simpler and less costly than prior art systems.

[0008] The need is met according to the present invention by providing a display system that includes a light source for providing illumination; a linear array of electromechanical grating devices of at least two individually operable devices receiving the illumination, wherein a grating period is oriented at a predetermined angle with respect to an axis of the linear array wherein the angle is large enough to separate diffracted light beams prior to a lens system for projecting light onto a screen; an obstructing element for blocking a discrete number of diffracted light beams from reaching the

screen; a scanning element for moving non-obstructed diffracted light beams on the screen; and a controller for providing a data stream to the individually operable devices.

[0009] The present invention has several advantages, including: 1) improvement in contrast by eliminating reflections from projection lens, because of the new flexibility in placing the turning mirror between the linear array and the projection lens; 2) reduction in size of the scanning mirror, because now the scanning mirror can be placed directly at the Fourier plane; 3) increase in design flexibility, because now separation of diffracted orders can take place almost anywhere in the system, not just at the Fourier plane; and 4) reduction in size of lenses and other optical elements.

Fig. 1 is a perspective, partially cut-away view of a spatial light modulator with electromechanical conformal grating devices, showing two devices in a linear array;

Fig. 2 is a top view of a spatial light modulator with electromechanical conformal grating devices, showing four individually operable devices in a linear array;

Figs. 3a and 3b are cross-sectional views through line 3-3 in Fig. 2, showing the operation of an electromechanical conformal grating device in an unactuated state and an actuated state, respectively;

Figs. 4a and 4b show the operation of a conventional electromechanical two-level grating device in an unactuated state and an actuated state, respectively;

Fig. 5 is a top view of a spatial light modulator with conventional GLV devices, showing five individually operable devices in a linear array with deformable ribbon elements oriented perpendicular to the axis of the array and the grating period oriented parallel to the axis;

Fig. 6 is a top view of a spatial light modulator with conventional GLV devices, showing five individually operable devices in a linear array with deformable ribbon elements oriented parallel to the axis of the array and the grating period oriented perpendicular to the axis;

Fig. 7 is a schematic illustrating a prior art, line-scanned Schleiren display system that includes a light source, illumination optics, a linear array of conventional GLV devices, a projection lens, a scanning mirror, a controller and a turning mirror located at the Fourier plane of the projection lens;

Fig. 8 is a schematic illustrating a line-scanned display system according to the present invention that includes a light source, illumination optics, a linear array of electromechanical conformal grating devices, a projection lens, a scanning mirror, a controller and a turning mirror located between the linear array and the projection lens;

Fig. 9 shows a linear array of electromechanical conformal grating devices illuminated by a line of light;

Fig. 10 is a view of the projection screen that illustrates the formation of a two-dimensional image by scanning a line image across the screen;

Figs. 11a - 11h are density plots of the light distribution in different planes of a prior art, line-scanned Schleiren display system in which the modulator is a linear array of conventional GLV devices with deformable ribbon elements oriented perpendicular to the axis of the array;

Figs. 12a - 12h are density plots of the light distribution in different planes of a line-scanned display system of the present invention in which the modulator is a linear array of electromechanical conformal grating devices;

Fig. 13 is a schematic illustrating an alternate embodiment of the present invention in which the turning mirror is placed between the first projection lens and the scanning mirror, and an intermediate image plane is formed in the system;

Fig. 14 is a schematic illustrating an optical subsystem for illumination and diffracted order separation in which the illumination optics, the linear array of electromechanical conformal grating devices, and the turning mirror are combined into a single mechanical structure;

Fig. 15 is a schematic illustrating an optical subsystem for illumination and diffracted order separation in which the turning mirror is replaced by a polarization beam splitter, a quarter waveplate and a 0^{th} order stop;

Fig. 16 is a schematic illustrating a color, line-scanned display system that includes a three-color light source, illumination optics, a color combination cube, three linear arrays of electromechanical conformal grating devices, a projection lens, a scanning mirror and a turning mirror located between the linear arrays and the projection lens,

Fig. 17 is a schematic illustrating a color, line-scanned display system with three light sources;

Fig. 18 is a schematic illustrating a printer system that includes a light source, illumination optics, a linear array of electromechanical conformal grating devices, an imaging lens, a rotating drum, light sensitive media, a controller and a turning mirror located between the linear array and the projection lens; and

Fig. 19 is a schematic illustrating a color printer system with a three-color light source, a color combination cube and three linear arrays of electromechanical conformal grating devices.

[0010] The structure and operation of an electromechanical conformal grating device is illustrated in Figs. 1-3. Fig. 1 shows two side-by-side conformal grating devices 5a and 5b in an unactuated state. In this embodiment, the devices can be operated by the application of an electrostatic force. The grating devices **5a** and **5b** are formed on top of a substrate **10** covered by a bottom conductive layer **12** which acts as an electrode to actuate the devices. The bottom

conductive layer **12** is covered by a dielectric protective layer **14** followed by a standoff layer **16** and a spacer layer **18.** On top of the spacer layer **18**, a ribbon layer **20** is formed which is covered by a reflective layer **22.** The reflective layer **22** is also a conductor in order to provide electrodes for the actuation of the conformal grating devices **5a** and **5b.** The reflective and conductive layer **22** is patterned to provide electrodes to the two conformal grating devices **5a** and **5b**. The ribbon layer **20** preferably comprises a material with a sufficient tensile stress to provide a large restoring force. Each of the two devices **5a** and **5b** has an associated elongated ribbon element **23a** and **23b,** respectively, patterned from the reflective and conductive layer **22** and the ribbon layer **20.** The elongated ribbon elements **23a** and **23b** are supported by end supports **24a** and **24b** formed from the spacer layer **18** and by one or more intermediate supports **27** that are uniformly separated in order to form four equal-width channels **25.** The elongated ribbon elements **23a** and **23b** are secured to the end supports and to the intermediate supports **27.** A plurality of square standoffs **29** is patterned at the bottom of the channels **25** from the standoff layer **14.** These standoffs **29** reduce the possibility of the ribbon elements sticking when actuated.

[0011] A top view of a four-device linear array of conformal grating devices **5a, 5b, 5c** and **5d** is shown in Fig. 2. The elongated ribbon elements are depicted partially removed over the portion of the diagram below the line 2-2 in order to show the underlying structure. For best optical performance and maximum contrast, the intermediate supports **27** must be completely hidden below the elongated ribbon elements **23a, 23b, 23c** and **23d.** Therefore, when viewed from the top, the intermediate supports must not be visible in the gaps **28** between the conformal grating devices **5a-5d.** Here each of the conformal grating devices has three intermediate supports **27** with four equal-width channels **25.** The center-to-center separation Λ of the intermediate supports **27** defines the period of the conformal grating devices in the actuated state. The elongated ribbon elements **23a-23d** are mechanically and electrically isolated from one another, allowing independent operation of the four conformal grating devices **5a-5d.** The bottom conductive layer **12** of Fig. 1 can be common to all of the devices.

[0012] Fig. 3a is a side view, through line 3-3 of Fig. 2, of two channels **25** of the conformal grating device **5b** (as shown and described in Fig. 1) in the unactuated state. Fig. 3b shows the same view of the actuated state. For operation of the device, an attractive electrostatic force is produced by applying a voltage difference between the bottom conductive layer **12** and the conducting layer **22** of the elongated ribbon element **23b.** In the unactuated state (see Fig. 3a), with no voltage difference, the ribbon element **23b** is suspended flat between the supports. In this state, an incident light beam **30** is primarily diffracted into a 0th order light beam **32** in the mirror direction. To obtain the actuated state, a voltage is applied to the conformal grating device **5b,** which deforms the elongated ribbon element **23b** and produces a partially conformal grating with period Λ. Fig. 3b shows the device **5b** (as shown and described in Fig. 1) in the fully actuated state with the elongated ribbon element **23b** in contact with the standoffs **29.** The height difference between the bottom of element **23b** and the top of the standoffs **29** is chosen to be approximately ¼ of the wavelength λ of the incident light. The optimum height depends on the specific shape of the actuated device. In the actuated state, the incident light beam **30** is primarily diffracted into the +1st order light beam **35a** and -1st order light beam **35b,** with additional light diffracted into the +2nd order **36a** and -2nd order **36b.** A small amount of light is diffracted into even higher orders and some is diffracted into the 0th order. One or more of the diffracted beams can be collected and used by the optical system, depending on the application. When the applied voltage is removed, the forces due to the tensile stress and bending restores the ribbon element **23b** to its original unactuated state.

[0013] A linear array of conformal grating devices is formed by arranging the devices as illustrated in Figs. 1-3 with the direction of the grating period Λ (the y direction) perpendicular to the axis of the array (the x direction). For a given incident angle, the planes containing the various diffracted light beams are distinct. These planes all intersect in a line at the linear array. Even with a large linear array consisting, possibly, of several thousand devices illuminated by a narrow line of light, the diffracted light beams become spatially separated over a relatively short distance. This feature simplifies the optical system design and enables feasible designs in which the separation of diffracted light beams can be done spatially without Schlieren optics.

[0014] A conventional Grating Light Valve (GLV) is shown in Figs. 4a and 4b. Fig. 4a depicts the ribbon structure of the device in the unactuated state and Fig. 4b in the actuated state. For operation of the device, an attractive electrostatic force is produced by a voltage difference between the bottom conductive layer **42** and the reflective and conductive layer **48** atop the ribbon element **46.** In the unactuated state, with no voltage difference, all of the ribbon elements **46** in the GLV device are suspended above the substrate **40** at the same height. In this state, an incident light beam **54** is primarily reflected as from a mirror to form a 0th order diffracted light beam **55.** To obtain the actuated state (see Fig. 4b), a voltage is applied to every other ribbon element **46** producing a grating. In the fully actuated state, every other ribbon element **46** is in contact with the protective layer **44.** When the height difference between adjacent ribbons is ¼ of the wavelength of an incident light beam 56, the light beam is primarily diffracted into a +1st order light beam **57** and a -1st order light beam **58.** One or more of the diffracted beams can be collected and used by an optical system, depending on the application. When the applied voltage is removed, the force due to the tensile stress restores the ribbon elements **46** to their original unactuated state (see Fig. 4a).

[0015] The table below summarizes the key differences between a conformal grating device and a conventional GLV

for a single device of each type.

	Conformal grating device	Conventional GLV
# of moving ribbons	1	3 - 6
# of stationary ribbons	none	3 - 6
Number of channels	> 5	1
Grating period direction	Parallel to ribbon length	Perpendicular to ribbon length
Grating profile	Smoothly varying	Square (binary)

It should be noted that the parameters above pertain to the preferred forms of each of the devices.

[0016] In a linear array made from conventional GLV devices, the ribbon elements are usually all arranged parallel to each other. Fig. 5 shows the top view of a portion of such a linear array. In this example, each of 5 devices **45a, 45b, 45c, 45d** and **45e** contains 4 movable ribbon elements **46a** that are electrically connected to each other and 4 stationary ribbon elements **46b** that are connected to ground. The application of a voltage to a device causes the movable ribbon elements **46a** belonging to that device to actuate in unison into the channel **50.** The grating period Λ formed by the actuated ribbons is parallel to the axis of the array and perpendicular to the length of the ribbon elements **46a** and **46b.** The diffracted light beams then overlap spatially over a relatively long distance.

[0017] As a comparative example between the two types of linear arrays, let us consider an array of conformal grating devices that is 4 cm long (2000 devices 20 μm wide) illuminated by a 100 μm wide line of light. For devices with a period chosen such that the diffracted orders are angularly separated by 1 degree, the orders will become spatially separated in approximately 6 mm. This rapid separation of diffracted orders occurs because the grating period is perpendicular to the axis of the linear array of conformal grating devices, and is parallel to the length of the ribbon elements. A similar 4 cm linear array of prior art GLV devices with a 4 degree angular separation between diffracted orders would require at least 60 cm for spatial separation, without the use of a Schlieren optical system. This relatively slow order separation occurs because the grating period is parallel to the axis of the linear array of GLV devices.

[0018] A linear array of GLV devices can also be constructed with the ribbons elements perpendicular to the axis of the array as illustrated in Fig. 6. Each of the 5 devices **62a, 62b, 62c, 62d** and **62e** is individually operable and has its own channel **60a, 60b, 60c, 60d** and **60e.** For such a GLV array, the grating period Λ is perpendicular to the axis of the array and the diffracted light beams become spatially separated over a relatively short distance. However, this type of GLV array suffers from the existence of significant gaps between devices that cause some pixelation in the display.

[0019] Fig. 7 shows a GLV-based display system of the prior art that has a Schlieren optical system. The linear array **85** consists of GLV devices of the type shown in Fig. 5. Light is emitted from a source **70** and passes through a spherical lens **72** and a cylinder lens **74** before hitting a turning mirror **82.** The turning mirror **82** is placed at the Fourier (focal) plane of a projection lens system **75.** Although only a single lens element is shown, in practice, the projection lens system will consist of multiple elements. Light reflected by the turning mirror **82** is focused by the projection lens system **75** into a line illuminating the linear array **85.** A small portion of the illumination that strikes the projection lens system **75** will be reflected. In order to avoid a reduction in the contrast of the display system from such reflections, the projection lens system **75** needs to have very good optical coatings and/or needs to be used off axis. The GLV devices of the linear array **85** are selectively activated by the controller **80** to correspond to a line of pixels. If a particular device of the array is actuated by application of a voltage to the ribbon elements, it diffracts light primarily into +1st order and -1st order light beams. If a particular device is not actuated, it diffracts light primarily into the 0th order light beam. These three primary light beams are collected by the same projection lens **75,** which focuses the three light beams into distinct spots at the Fourier plane. The 0th order light beam hits the turning mirror **82** and is reflected towards the light source **70.** The +1st and -1st order light beams pass above and below the turning mirror **82** and strike a scanning mirror **77** that sweeps the light beams across a screen **90** to form a viewable two-dimensional image. Higher-order light beams also show up as spots in the Fourier plane and can be blocked from reaching the screen **90** by a stop in the Fourier plane (not shown). The controller **80** synchronizes the sweep of the scanning mirror **77** with the actuation of the devices of the linear array **85.**

[0020] In the prior art display system of Fig. 7, in order to effectively separate the +1st and -1st order light beams from the 0th order light beam, the turning mirror **82** must be placed near the Fourier plane of the projection lens system **75,** i.e., it must be located at approximately the focal distance f from the lens. However, this location is also best for placing the scanning mirror **77** because the +1st and -1st order light beams are tightly focused here, allowing for a reduction in the size and weight of the scanning mirror **77.**

[0021] Figs. 8-10 illustrate the preferred embodiment of the present invention. Fig. 8 shows the display system with a turning mirror **82** placed between the linear array **85** and the projection lens system **75.** Light emitted by source **70** is conditioned by a spherical lens **72** and a cylindrical lens **74** before hitting the turning mirror **82** and focusing on the

linear array **85.** In this system, the axis of the cylindrical lens is rotated 90 degrees with respect to the cylindrical lens in Fig. 7. By placing the turning mirror **82** between the linear array **85** and the projection lens system **75,** the contrast-reducing reflections of the prior art system of Fig. 8 are eliminated because the illuminating light beam never passes through the projection lens system **75.** Fig. 9 shows the linear array **85** illuminated by a line of light **88.** In this particular example there are 17 electromechanical conformal grating devices shown. In practice, there would be hundreds or thousands of devices. The controller **80** selects the devices to be actuated based on the desired pixel pattern for a given line of a two-dimensional image. If a particular device is not actuated, it diffracts the incident light beam primarily into the 0th order light beam, which subsequently hits the turning mirror **82** and is reflected towards the source **70.** If the device is actuated, it diffracts the incident light beams primarily into +1st order and -1st order light beams. These two first-order diffracted light beams pass around the turning mirror **82** and are projected on the screen **90** by the projection lens system **75.** Higher-order diffracted light beams can be blocked by the addition of a stop **83.** The scanning mirror **77** sweeps the line image across the screen **90** to form the two-dimensional image. Preferably, the scanning mirror **77** is placed near the Fourier plane of the projection lens system **75.** Fig. 10 is a view facing the screen **90** showing the formation of a two-dimensional image from a series of 1080 sequential line scans.

[0022] Clearly, there are two kinds of diffracted light beams in this display system: those that are blocked by obstructing elements from reaching the screen **90** and those that pass around obstructing elements to form an image on the screen **90.** In this particular system, the obstructing elements are the turning mirror **82** that blocks the 0th order light beam and the stops **83** that block the ±2nd, ±3rd, ±4th, ...orders of light. In the subsequent embodiments, similar obstructing elements are used to prevent unwanted diffracted light beams from reaching the screen. However, as is well known to those skilled in the art, other elements may be used for this purpose. For example, the stops **83** can be replaced by tilted mirrors.

[0023] The linear array **85** is preferably constructed of electromechanical conformal grating devices of the type shown in Figs. 1-3. It may also be constructed of GLV devices of the type shown in Fig. 6, or of other kinds of electromechanical grating devices. However, in order to place the turning mirror **82** before the projection lens system **75,** the grating period Λ must be rotated at a sufficiently large angle with respect to the long axis of the linear array **85.** For the electromechanical conformal grating devices of Figs. 1-3 and the GLV devices of Fig. 6, this angle is 90 degrees. A lesser angle can also be used so long as the diffracted orders become separated before reaching the projection lens system **75.** It is impractical, however, to make this type of display system with no rotation between the grating period and the axis of the linear array **85.** A conventional linear array of GLV devices of the type shown in Fig. 5 can therefore not be used with this kind of system.

[0024] The significant differences between the display system of the prior art (Fig. 7) and the present display system (Fig. 8) can be understood by examining the propagation of the diffracted light beams throughout the two systems. Figs. 11a-11h show the amplitude of the diffracted light beams along several parallel planes between the linear array **85** and the screen **90** for the prior art system of Fig. 7. In this modeled example, the lens has a focal length f of 50 mm, the linear array is 1 cm long. D refers to the distance between the linear array **85** to the plane of interest. As the diffracted light beams emerge from the linear array **85,** they begin to spread along the direction of the axis of the linear array as illustrated in Figs. 11a-11d. The interference between the various diffracted beams causes a rapid variation in the intensity known to those skilled in the art as tilt fringes. At the plane just before the projection lens (see Fig. 11d), the diffracted light beams have spread to about twice the length of the linear array. The lens must be large enough to avoid truncating the diffracted light beams to be projected on the screen, which are the -1st and +1st order light beams in this case. After passing through the projection lens system **75,** the beams begin to focus. At a distance of D = 90 mm from the linear array **85,** the various diffracted orders are spatially separated. Distinct spots are visible that correspond to the +3rd, +2nd, +1st, 0th, -1st, -2nd and -3rd orders (see Fig. 11g). At the Fourier plane (D = 100 mm), the turning mirror 82 blocks the 0th order light beam and a stop blocks the +3rd, +2nd, -2nd and -3rd orders. The +1st and -1st order light beams continue towards the screen **90** where they overlap spatially to form the line image. It is important to note that the various order light beams are only spatially separated near the Fourier plane (near D = 100 mm). Therefore, only the vicinity of this plane is available for separating the +1st and - 1st order light beams from the rest of the diffracted orders.

[0025] Figs. 12a-12h show the amplitude of the diffracted light beams along several parallel planes for the display system of Fig. 8. In contrast to the prior art display system, as the various diffracted light beams propagate from one plane to the next, they spread out in a direction perpendicular to the axis of the linear array **85.** They become spatially separated a few millimeters from the linear array **85** and remain spatially separated throughout the system, except near the screen **90** and any intermediate image planes. Fig. 12d shows the light distribution just before the turning mirror **82** and the stop **83,** which block the unwanted diffracted orders. Only the +1st and -1st order light beams pass through the projection lens system **75.** For better optical efficiency, higher diffracted orders could also be allowed through. Figs. 12e-12h show the +1st and -1st order light beams after they have gone through the projection lens system and pass through focus at the Fourier plane (D = 100 mm). Near the Fourier plane, the two first order light beams are tightly focused into two spots. Therefore, by placing the scanning mirror **77** here, it can be kept small and

light. The +1st and - 1st order light beams overlap spatially when they finally reach the screen **90**.

[0026] An alternate embodiment of the invention is shown in Fig. 13. The projection lens system now consists of 3 separate lens groups **75a**, **75b** and **75c**. The turning mirror **82** is placed between the first lens group **75a** and the scanning mirror **77** adjacent to the first lens group **75a**. This location for the turning mirror **82** can be beneficial because the diffracted light beams are collimated along one axis in this space. The cylinder lens axis **74** is rotated 90 degrees with respect to the cylinder lens of Fig. 8. The scanning mirror **77** is preferably placed at the Fourier plane (focal plane) of the first lens group **75a**. The second lens group **75b** creates an intermediate image **92** of the linear array 85 that can be used to modify the image appearing on the screen **90**. For example, an aperture can be placed in this plane to create a sharp boundary for the image. The third lens group **75c** projects the intermediate image **92** onto the screen **90**.

[0027] In order to the improve alignment and stability of the system, some of the optical elements can be combined into a solid structure and/or can be replaced by equivalent components. As an example, Fig. 14 shows the combination of several components of Fig. 8, namely, of the cylinder lens **74**, turning mirror **82**, stop **83** and linear array **85**. The turning mirror **82** may also be replaced by using a polarization beam splitter **96** with a ¼ waveplate **95** and a 0th order stop **97** as in Fig. 15.

[0028] The above embodiments can be used either for single color or for color-sequential display systems. For a color-sequential display, the light source **70** produces a plurality of colors that are sequential in time and the controller 80 is synchronized with the light source **70**. For example, if the light source **70** consists of three combined red, green and blue lasers, these are turned on sequentially to produce overlapping red, green and blue images on the screen **90**. The image data sent by the controller **80** to the linear array **85** is synchronized with the turned-on laser color.

[0029] Color-sequential display systems waste two-thirds of the available light because only one color is used at a time. Figs. 16 and 17 depict embodiments of the invention that project three colors simultaneously. In Fig. 16, the light source **70** emits red, green and blue. After these three colors hit the turning mirror **82**, they are separated by a color combination cube **100**. Red light illuminates linear array **85r**, green light linear array **85g** and blue light linear array **85b**. The +1st, 0th and -1st order light beams, emerging from the three linear arrays, are combined by the color combination cube **100**. The turning mirror **82** blocks the red, green and blue 0th order light beams after they pass through the cube. The remaining +1st and -1st order light beams are imaged by the projection lens system **75** to form a color image at the screen **90**. Three stops **83r**, **83g**, **83b** block unwanted higher-order diffracted light beams.

[0030] Alternatively, a color-simultaneous display system can be made with three distinct illumination paths as shown in Fig. 17. Three separate light sources **70r**, **70g**, **70b**, each with their own illumination optics **72r**, **72g**, **72**b, **74r**, 74g, 74b, provide light to the three linear arrays **85r**, **85g**, **85b** via three turning mirrors **82r**, **82g**, **82b**. The color combination cube **100** now serves only to combine the +1st and -1st order light beams of the three colors. In contrast to the display system of Fig. 17, the color combination cube **100** plays no role in illuminating the device.

[0031] The embodiments described above can be altered to obtain printing systems. For example, Fig. 18 shows a printer that is fashioned from the building blocks in Fig. 8. Light emitted by source **70** is conditioned by a spherical lens **72** and a cylindrical lens **74** before hitting the turning mirror **82** and focusing on the linear array **85** of electromechanical conformal grating devices. An imaging lens **105** is used at finite conjugates to create a line image of the linear array **85** on light sensitive media **110**. This line image is formed from the (non-obstructed) diffracted light beams that pass between the turning mirror **82** and the stops **83**. Although a scanning mirror **77** could be used to create a two-dimensional image from the line image, it is usually preferable to use a media transport system to move the light sensitive media **110** with respect to the line image. In Fig. 18, the media transport system has a rotating drum **107**. The motion of the media must be synchronized with the actuation of the electromechanical conformal grating devices of the linear array **85** by the controller **80**. This embodiment can be used for either a monochrome or a color-sequential printer. To obtain a high-speed printer that can print three colors simultaneously on photographic paper, three linear arrays are necessary. Fig. 19 shows an embodiment of a color-simultaneous printer fashioned from the building blocks in Fig. 16 with the following changes: an imaging lens **105** used at finite conjugates replaces the projection lens **75**, light sensitive media **110** replaces the screen **90** and a rotating drum **107** for moving the light sensitive media **110** replaces the scanning mirror **77**.

Claims

1. A display system, comprising:

   a light source providing illumination;
   a linear array of electromechanical grating devices of at least two individually operable devices receiving the illumination wherein a grating period is oriented at a predetermined angle with respect to an axis of the linear array wherein the angle is large enough to separate diffracted light beams prior to a lens system for projecting

light onto a screen;
an obstructing element for blocking a discrete number of diffracted light beams from reaching the screen;
a scanning element for moving non-obstructed diffracted light beams on the screen; and
a controller for providing a data stream to the individually operable devices.

2. The display system of claim 1, wherein the linear array is constructed of electromechanical conformal grating devices.

3. The display system of claim 1, wherein the linear array is constructed of electromechanical grating light valves.

4. The display system of claim 1, wherein the predetermined angle is defined to be perpendicular to the axis of the linear array.

5. The display system of claim 1, wherein the light source is of a single color.

6. The display system of claim 1, wherein the light source produces a plurality of colors that are sequential in time and the controller is synchronized with the light source.

7. The display system of claim 1, wherein the light source produces a plurality of colors at the same time and the display system includes a corresponding number of linear arrays of electromechanical grating devices.

8. The display system of claim 1 comprising at least three light sources and includes a corresponding number of linear arrays of electromechanical grating devices.

9. The display system of claim 1, wherein the obstructing element blocks a zeroth order diffracted light beam.

10. The display system of claim 9, wherein the obstructing element only allows first order diffracted light beams to reach the screen.

11. The display system of claim 1, wherein the obstructing element is placed between the linear array and a first lens of the lens system.

12. The display system of claim 1, wherein the obstructing element is placed after a first lens and before a Fourier plane of the lens system.

13. The display system of claim 1, wherein the scanning element is placed at a Fourier plane of the lens system and the obstructing element is placed between the linear array and the scanning element.

14. The display system of claim 1, wherein the light source is a laser.

15. The display system of claim 1, wherein the obstructing element is simultaneously used for delivery of light from the light source to the linear array.

16. The display system of claim 1, wherein the lens system includes an intermediate image plane after the scanning element wherein a two-dimensional image is formed and is relayed to the screen.

17. The display system of claim 15, wherein the obstructing element further includes:

a polarization sensitive beam splitter;
a waveplate; and
a stop to block a zeroth order diffracted light beam.

18. A display system, comprising:

a light source providing illumination;
a linear array of electromechanical conformal grating devices of at least two individually operable devices receiving the illumination wherein a grating period is oriented perpendicular to an axis of the linear array to separate diffracted light beams prior to a lens system for projecting light onto a screen;

an obstructing element for blocking a discrete number of diffracted light beams from reaching the screen;
a scanning element for moving non-obstructed diffracted light beams on the screen; and
a controller for providing a data stream to the individually operable devices.

19. The display system of claim 18, wherein the obstructing element blocks a zeroth order diffracted light beam.

20. The display system of claim 19, wherein the obstructing element only allows first order diffracted light beams to reach the screen.

21. The display system of claim 18, wherein the obstructing element is placed between the linear array and a first lens of the lens system.

22. The display system of claim 18, wherein the obstructing element is placed after a first lens and before a Fourier plane of the lens system.

23. The display system of claim 18, wherein the scanning element is placed at a Fourier plane of the lens system and the obstructing element is placed between the linear array and the scanning element.

24. The display system of claim 18, wherein the obstructing element is simultaneously used for delivery of light from the light source to the linear array.

25. The display system of claim 24, wherein the obstructing element further comprises:

a polarization sensitive beam splitter;
a waveplate; and
a stop to block a zeroth order diffracted light beam.

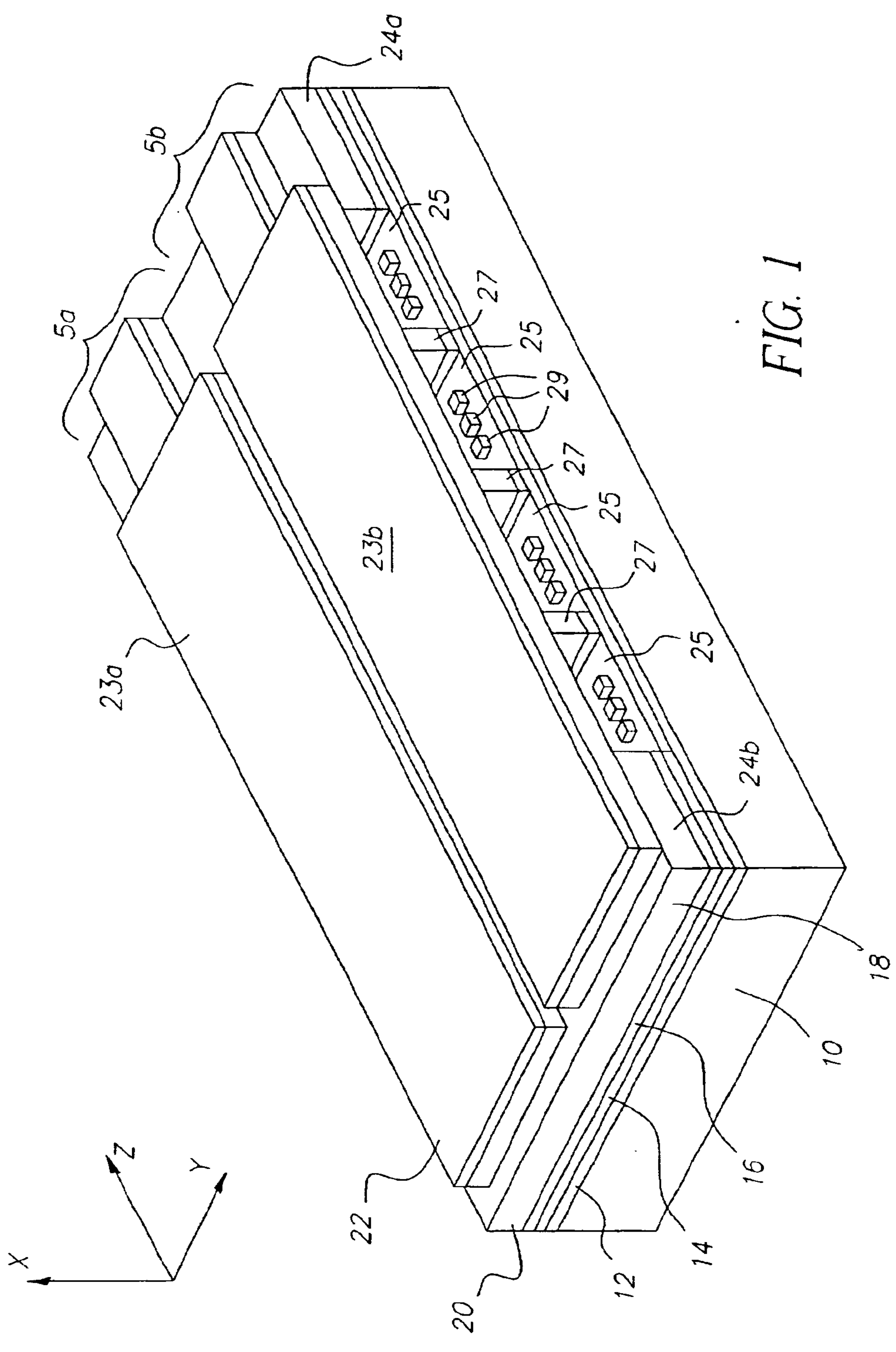


FIG. 1

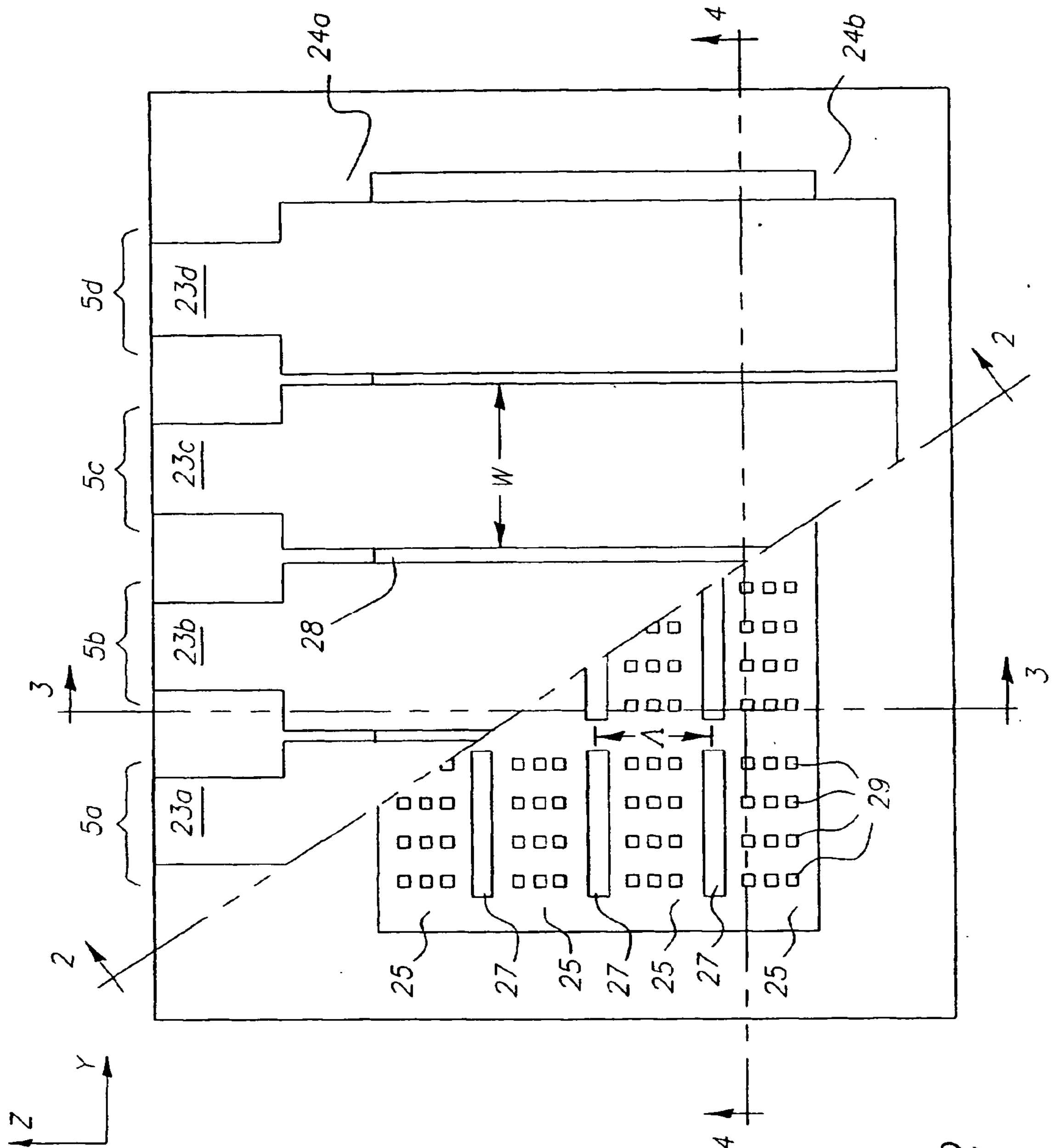
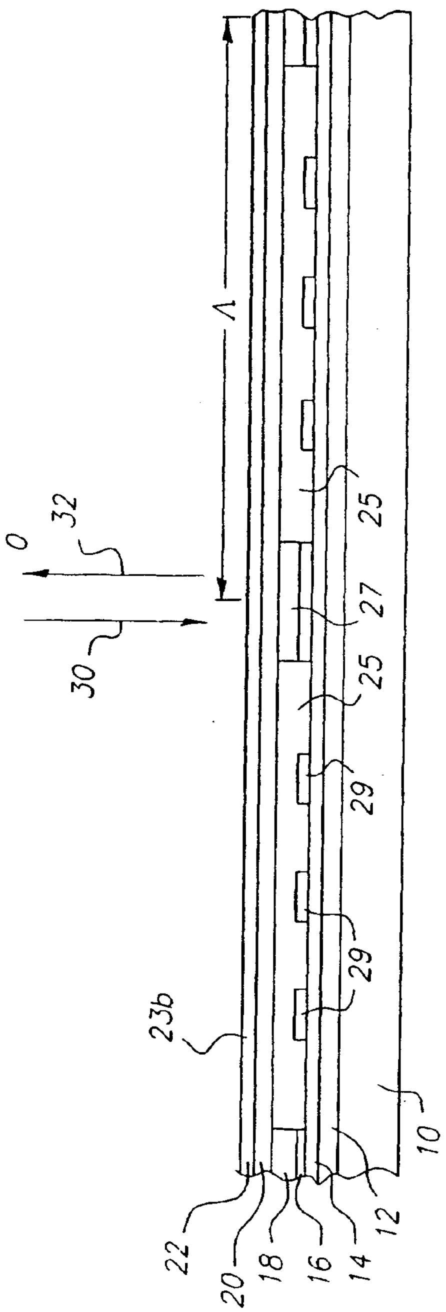


FIG. 2


30
32
0
Λ
25
27
25
29
29
29
23b
22
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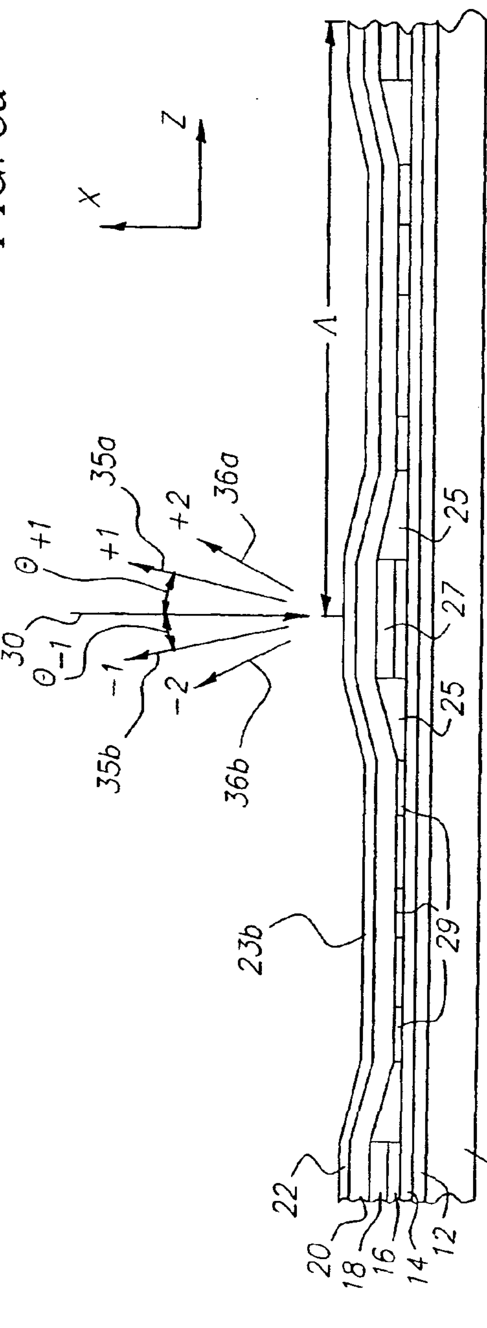
18
16
14
12
10

FIG. 3a


X
Z
Λ
30
θ_{+1}
+1
35a
+2
36a
θ_{-1}
−1
−2
35b
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27
25
29
23b
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20
18
16
14
12
10

FIG. 3b

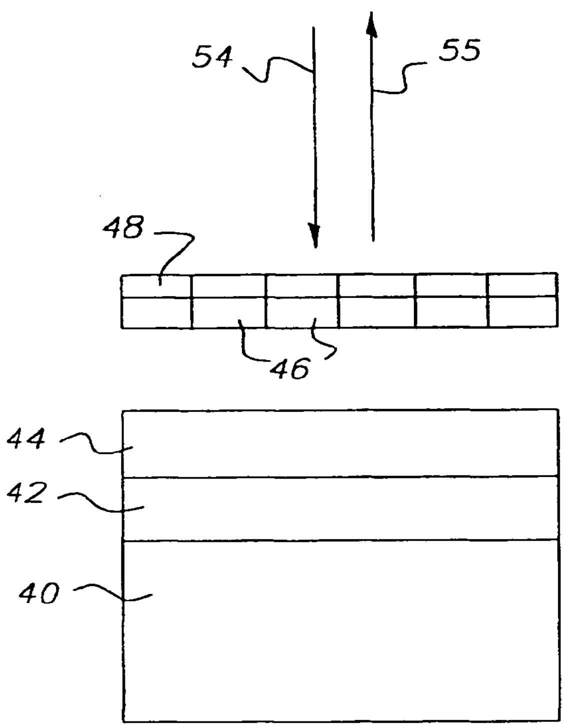


FIG. 4a
(PRIOR ART)

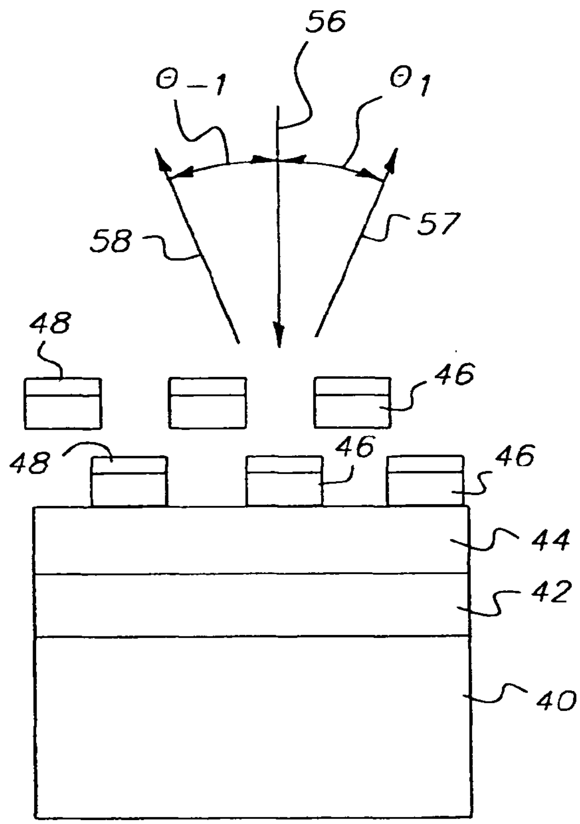


FIG. 4b
(PRIOR ART)

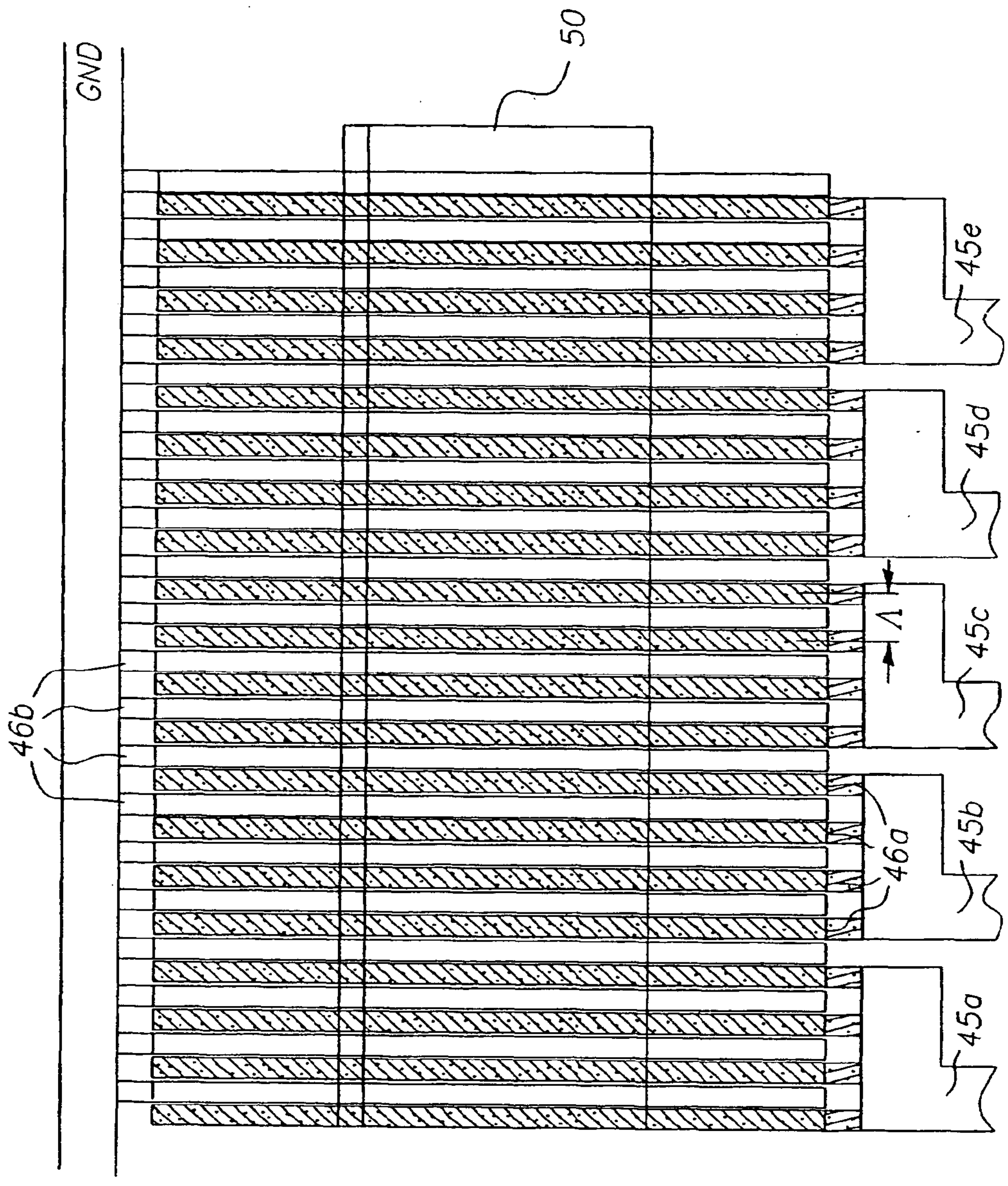


FIG. 5
(PRIOR ART)

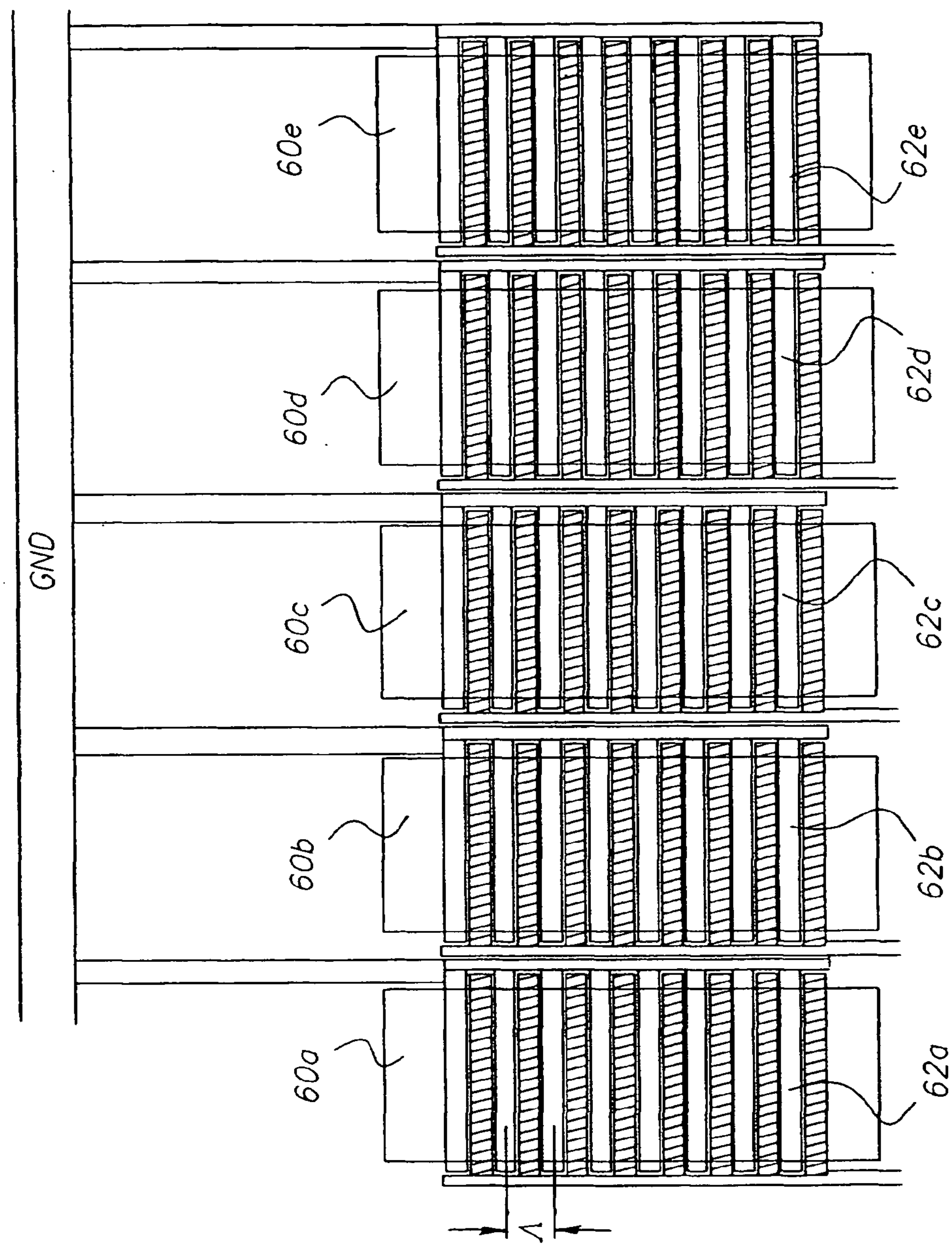


FIG. 6

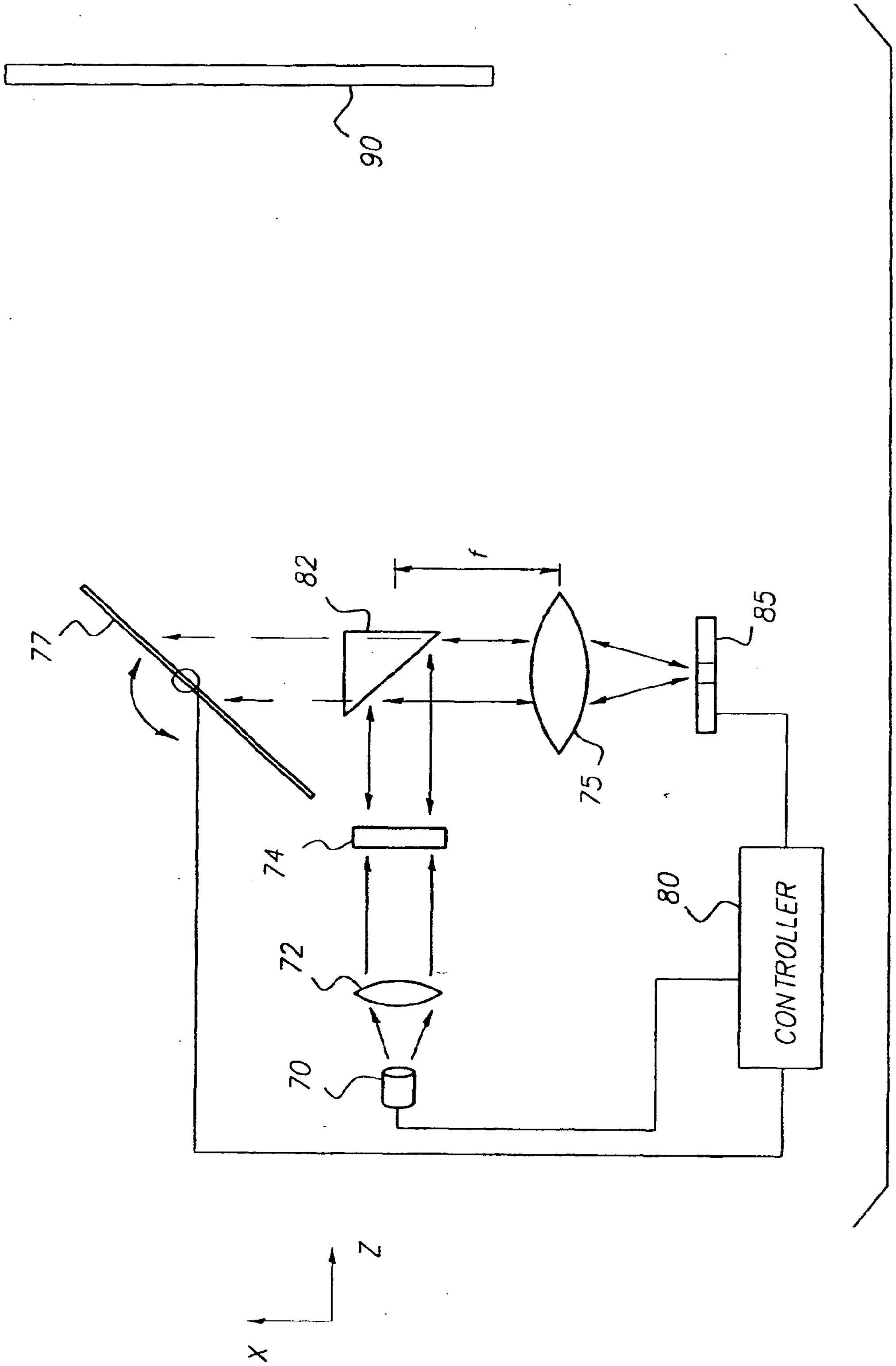


FIG. 7
(PRIOR ART)

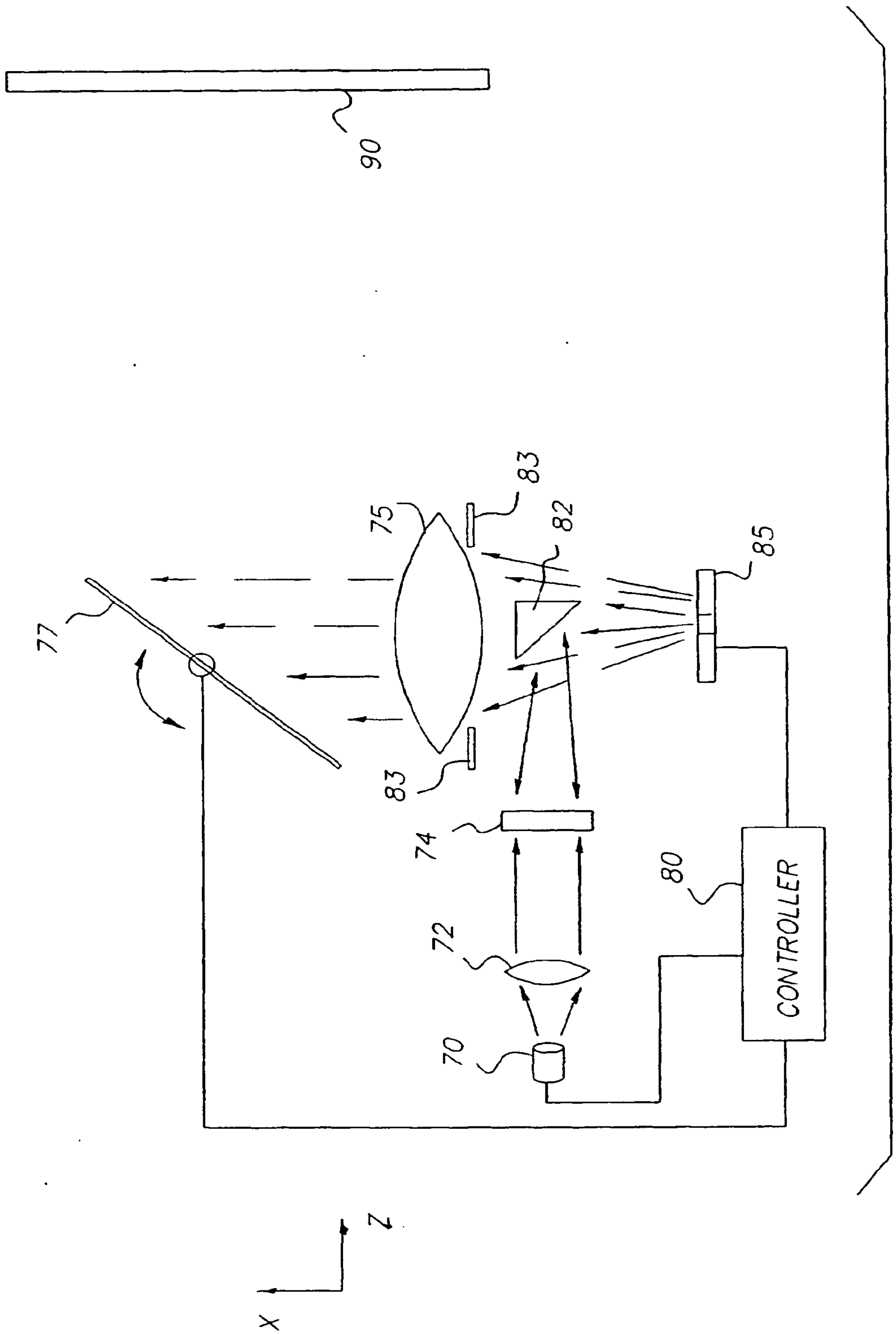


FIG. 8

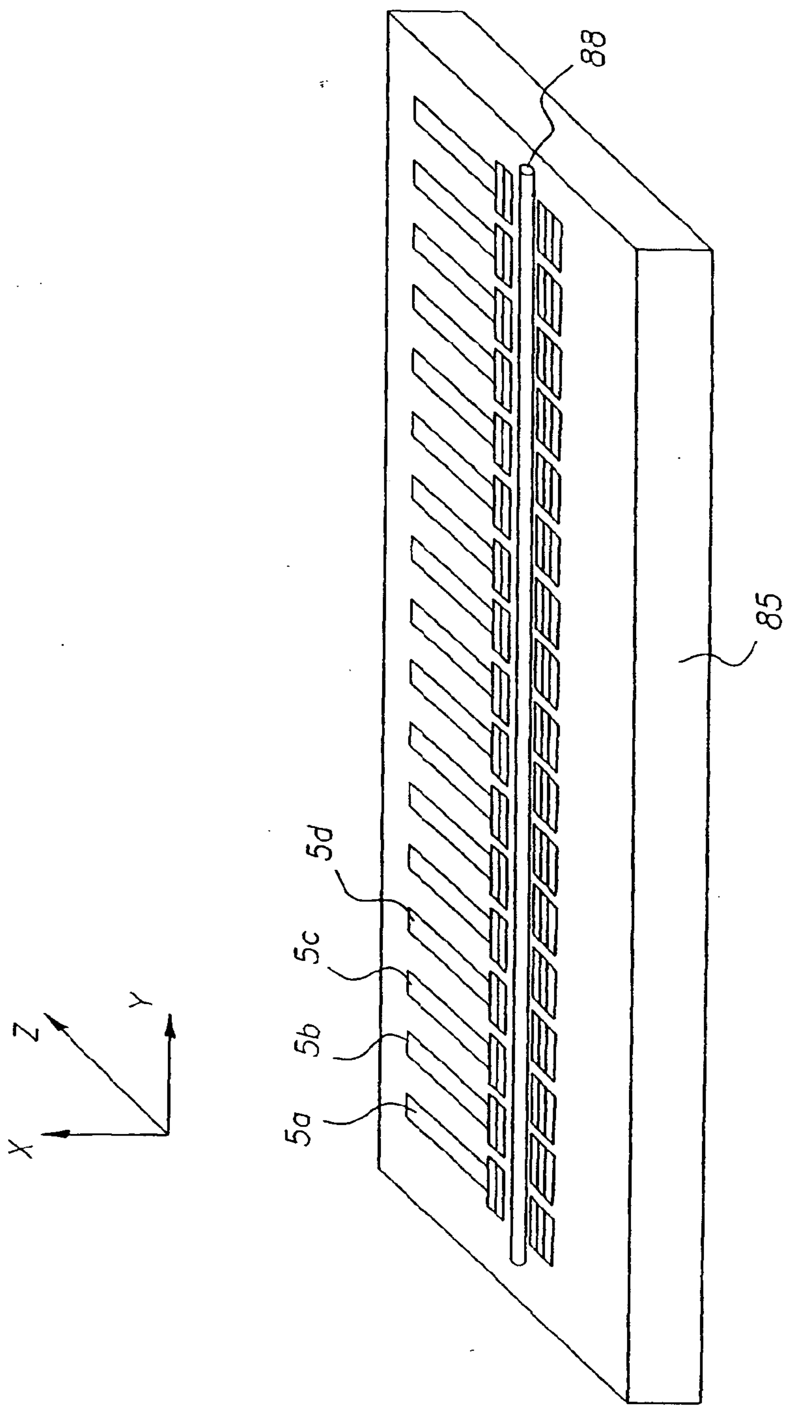


FIG. 9

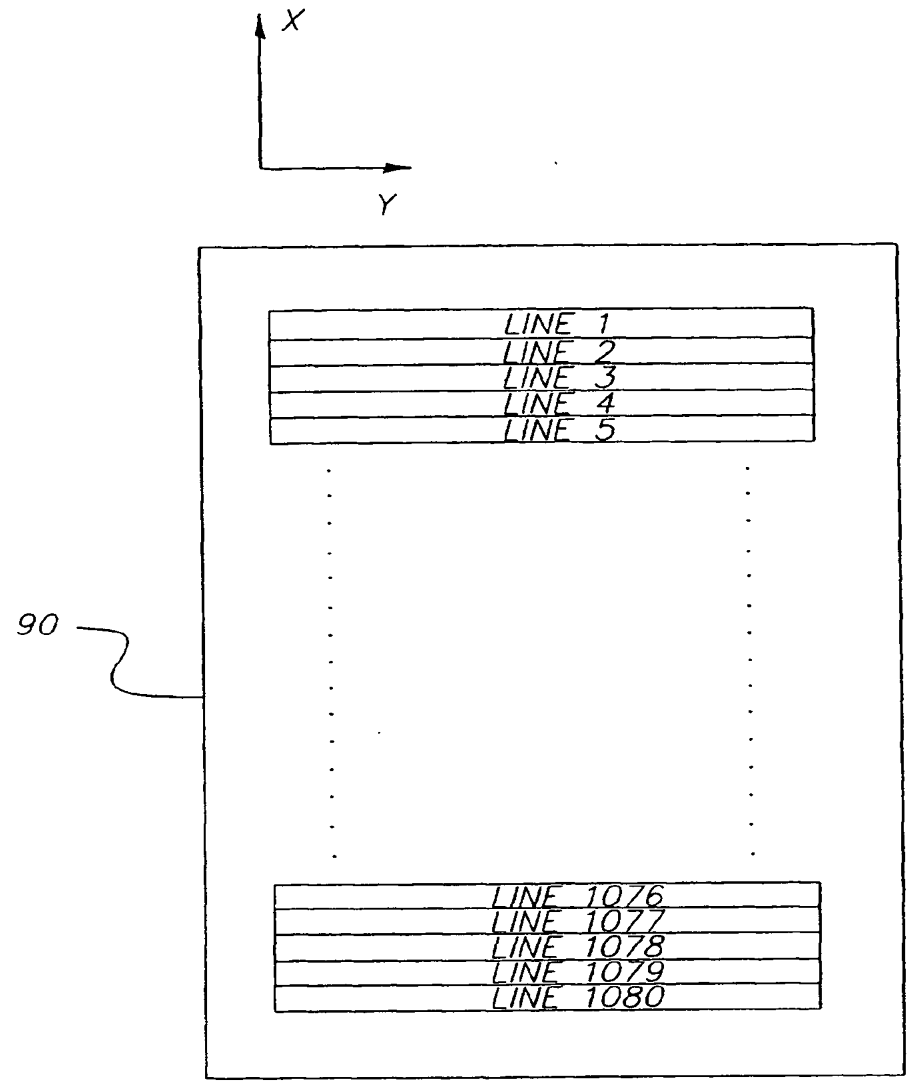

X
Y
LINE 1
LINE 2
LINE 3
LINE 4
LINE 5
LINE 1076
LINE 1077
LINE 1078
LINE 1079
LINE 1080
90

FIG. 10

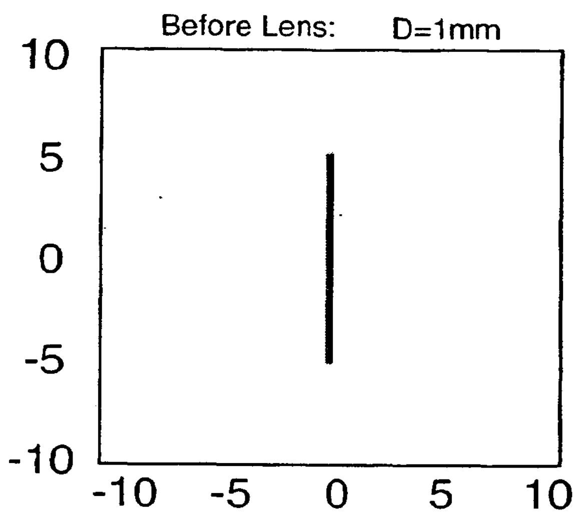


Fig. 11a

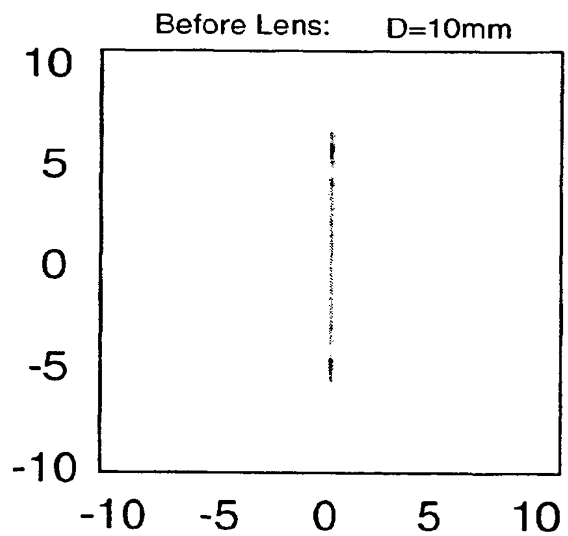


Fig. 11b

(Prior Art)

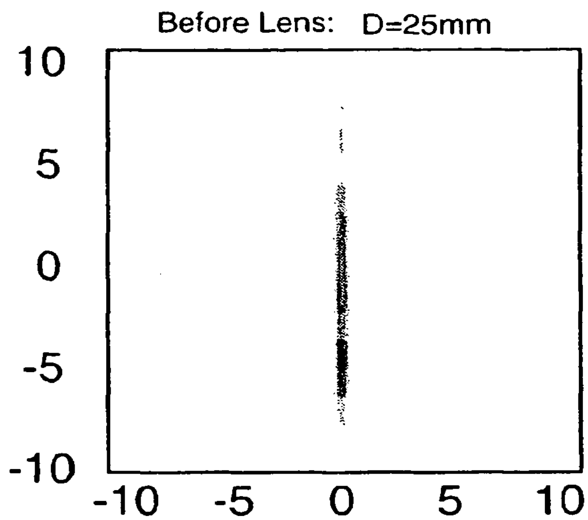


Fig. 11c

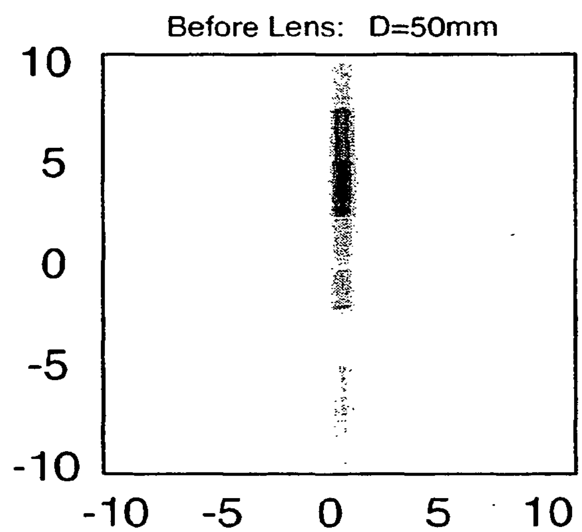


Fig. 11d

(Prior Art)

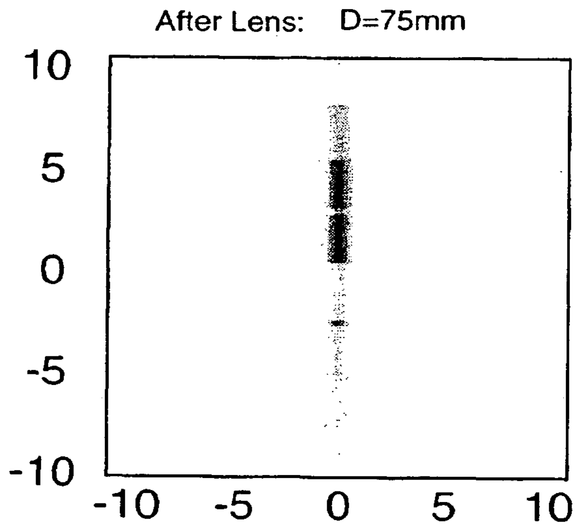


Fig. 11e

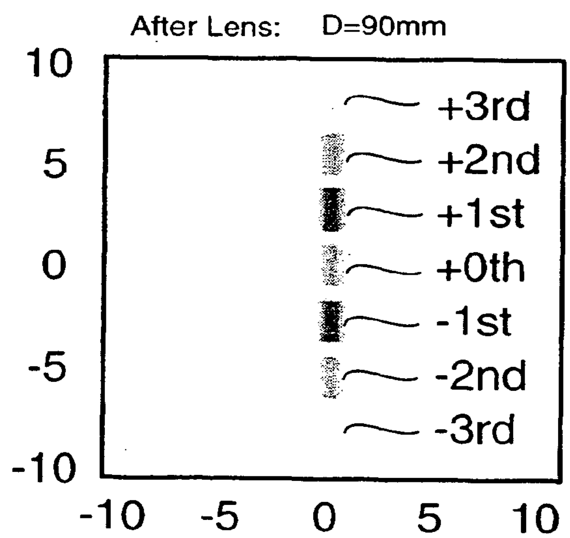


Fig. 11f

(Prior Art)

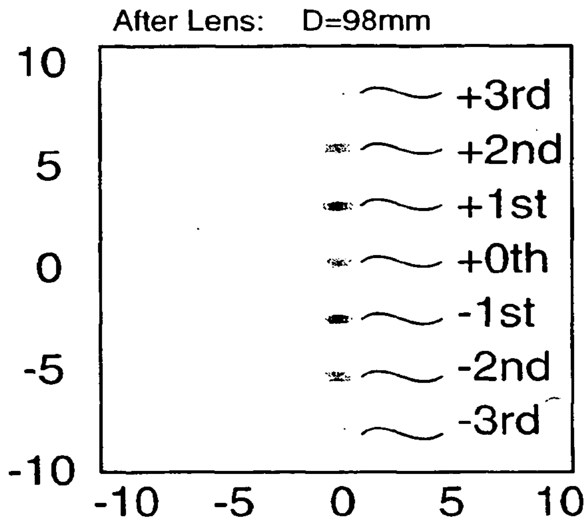


Fig. 11g

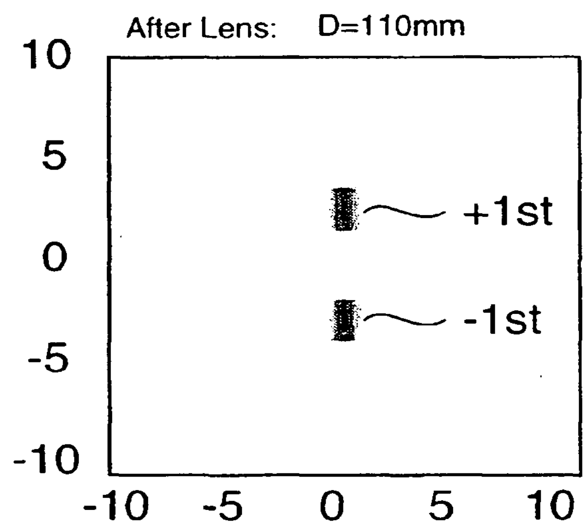


Fig. 11h

(Prior Art)

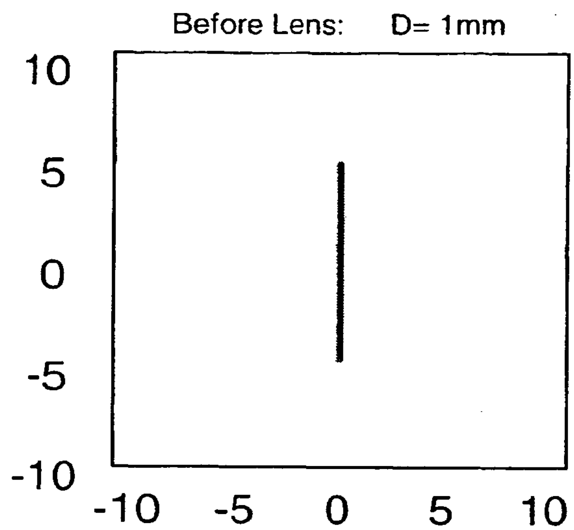


Fig. 12a

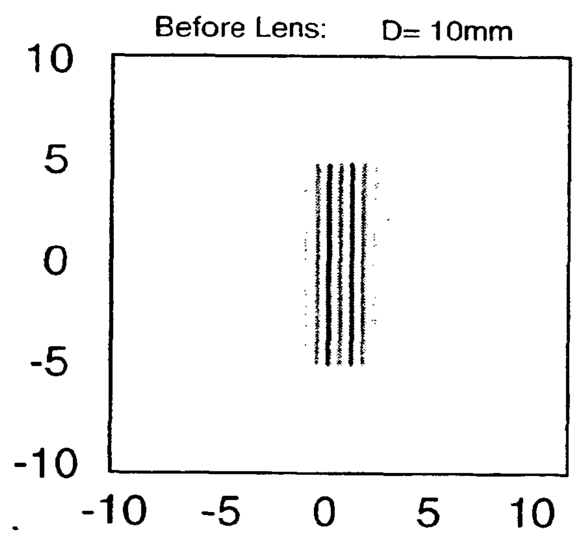


Fig. 12b

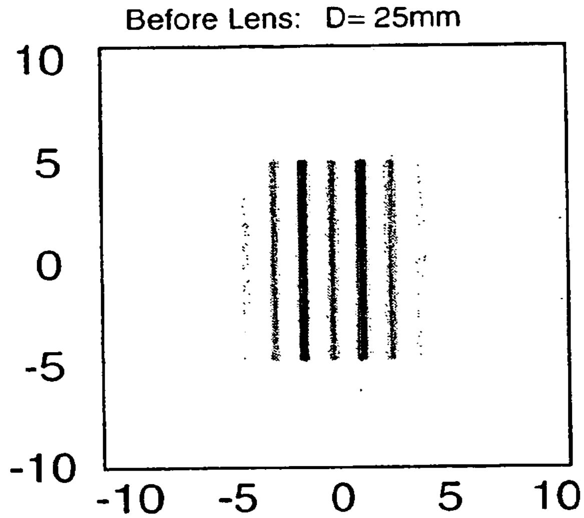


Fig. 12c

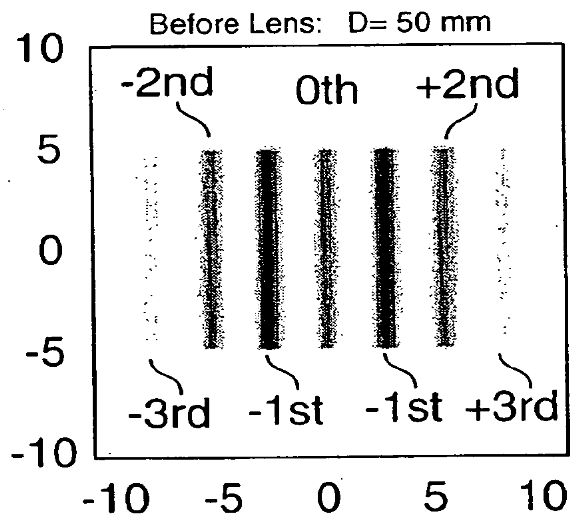


Fig. 12d

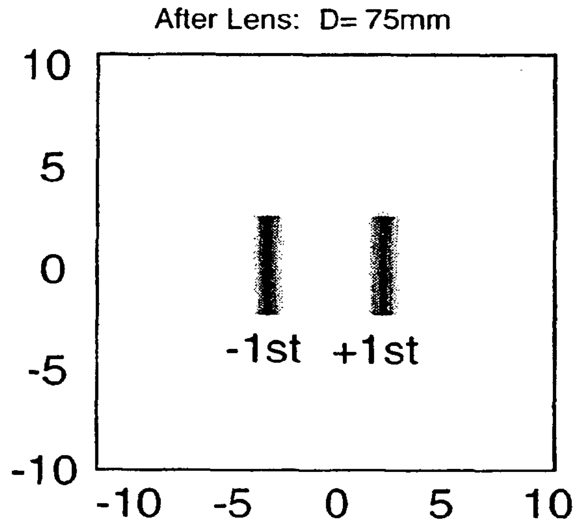


Fig. 12e

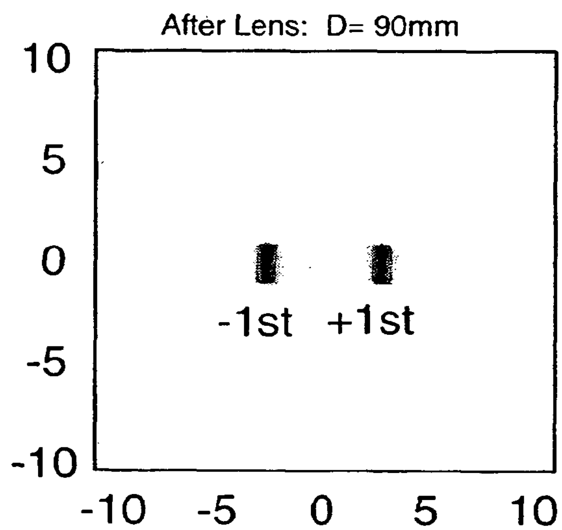


Fig. 12f

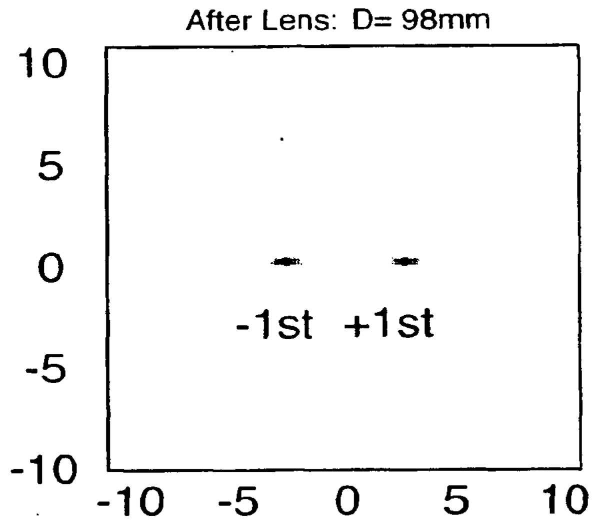


Fig. 12g

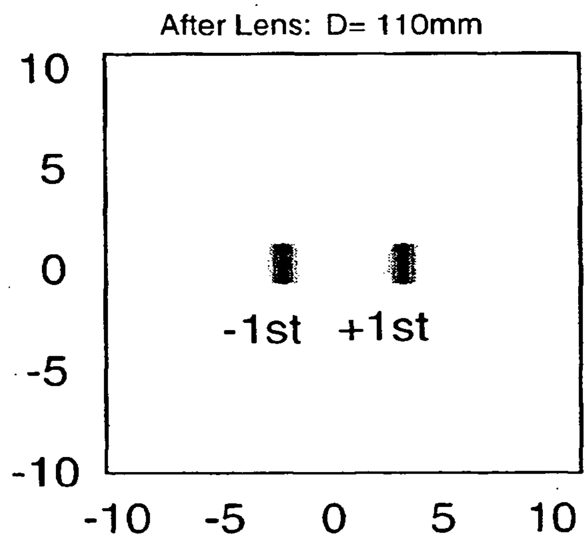


Fig. 12h

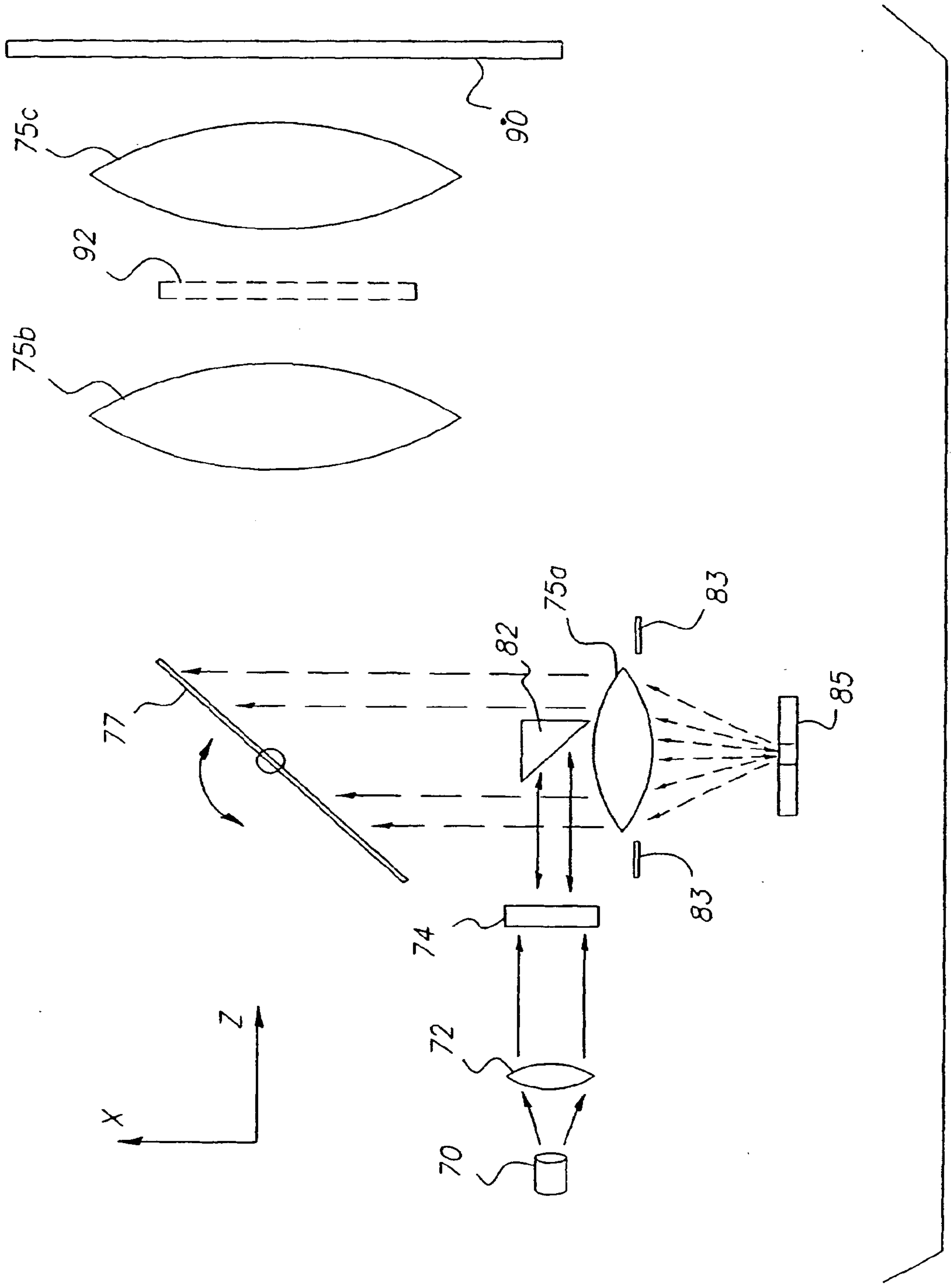


FIG. 13

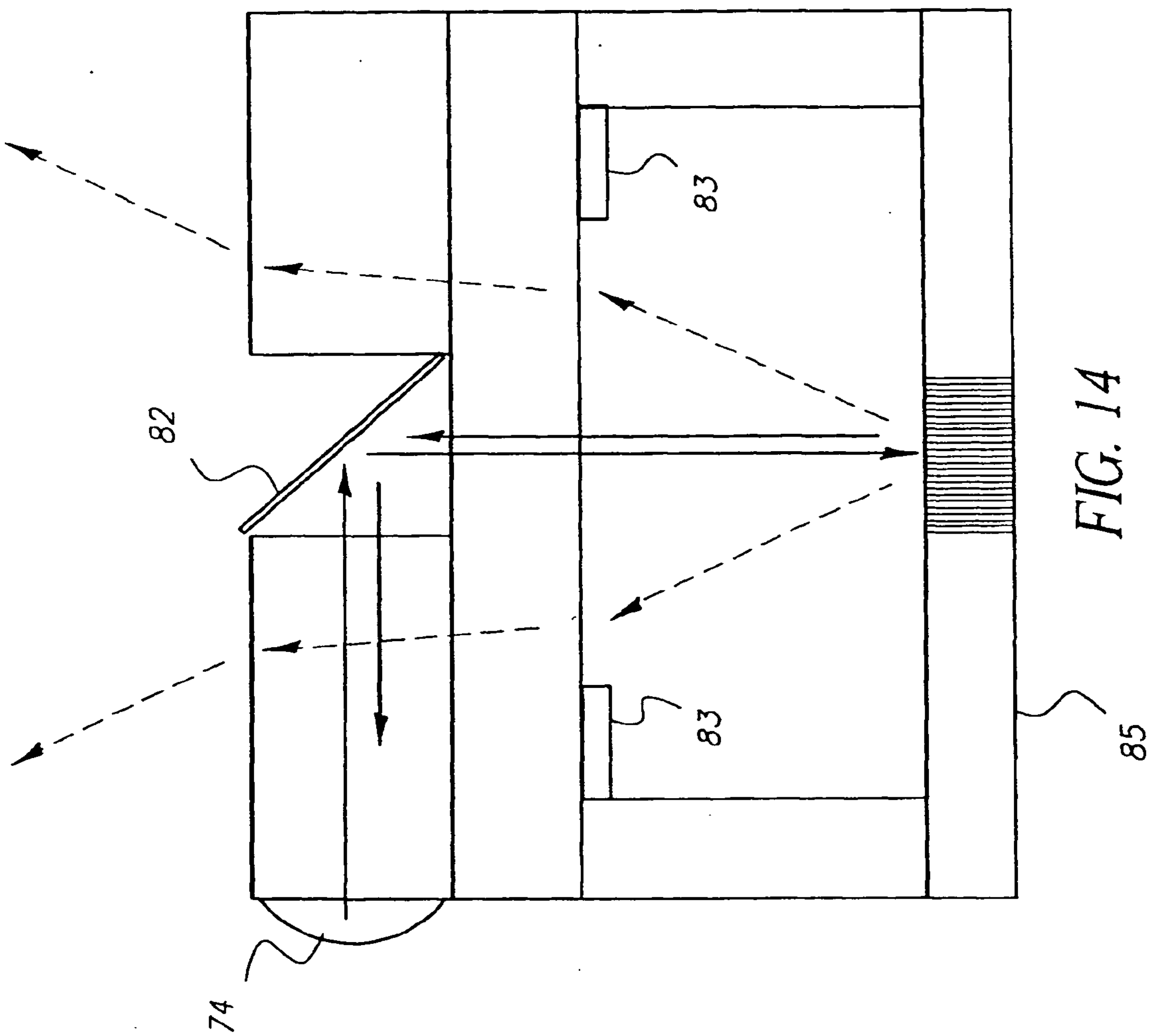


FIG. 14

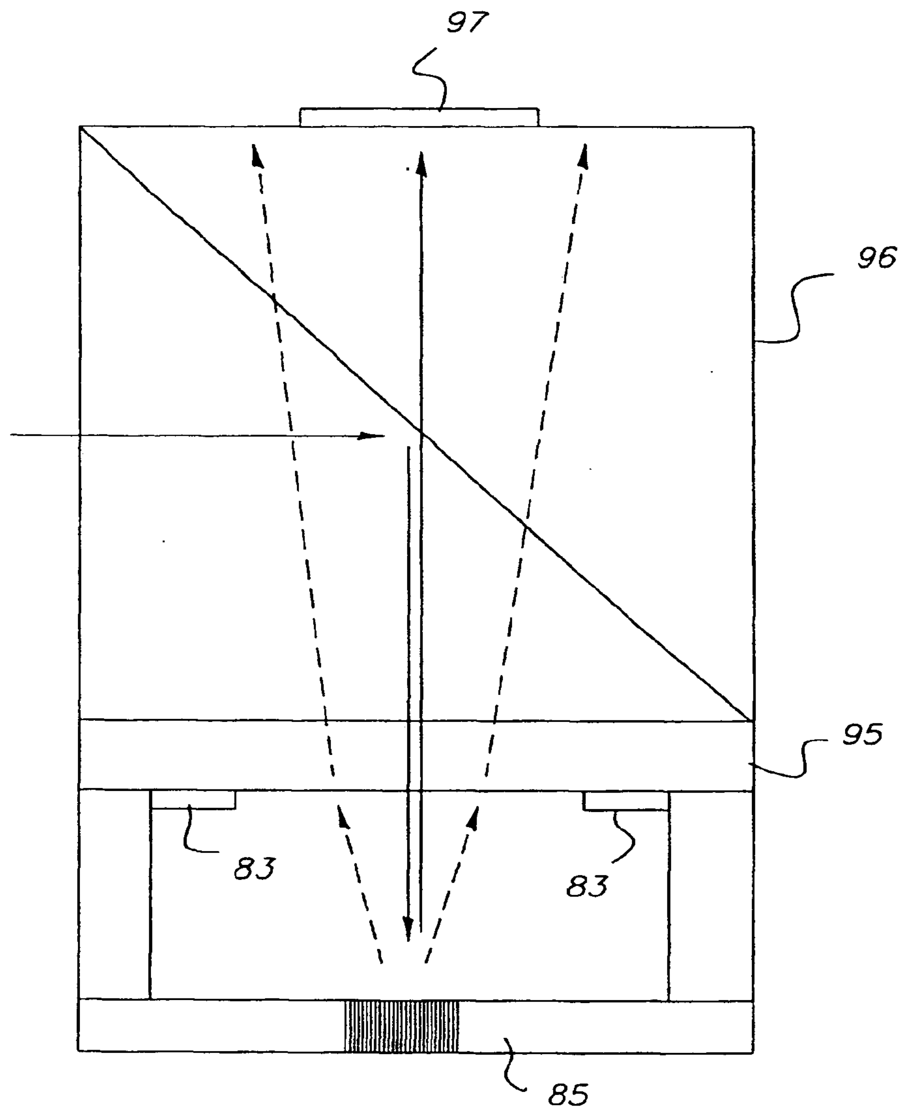


FIG. 15

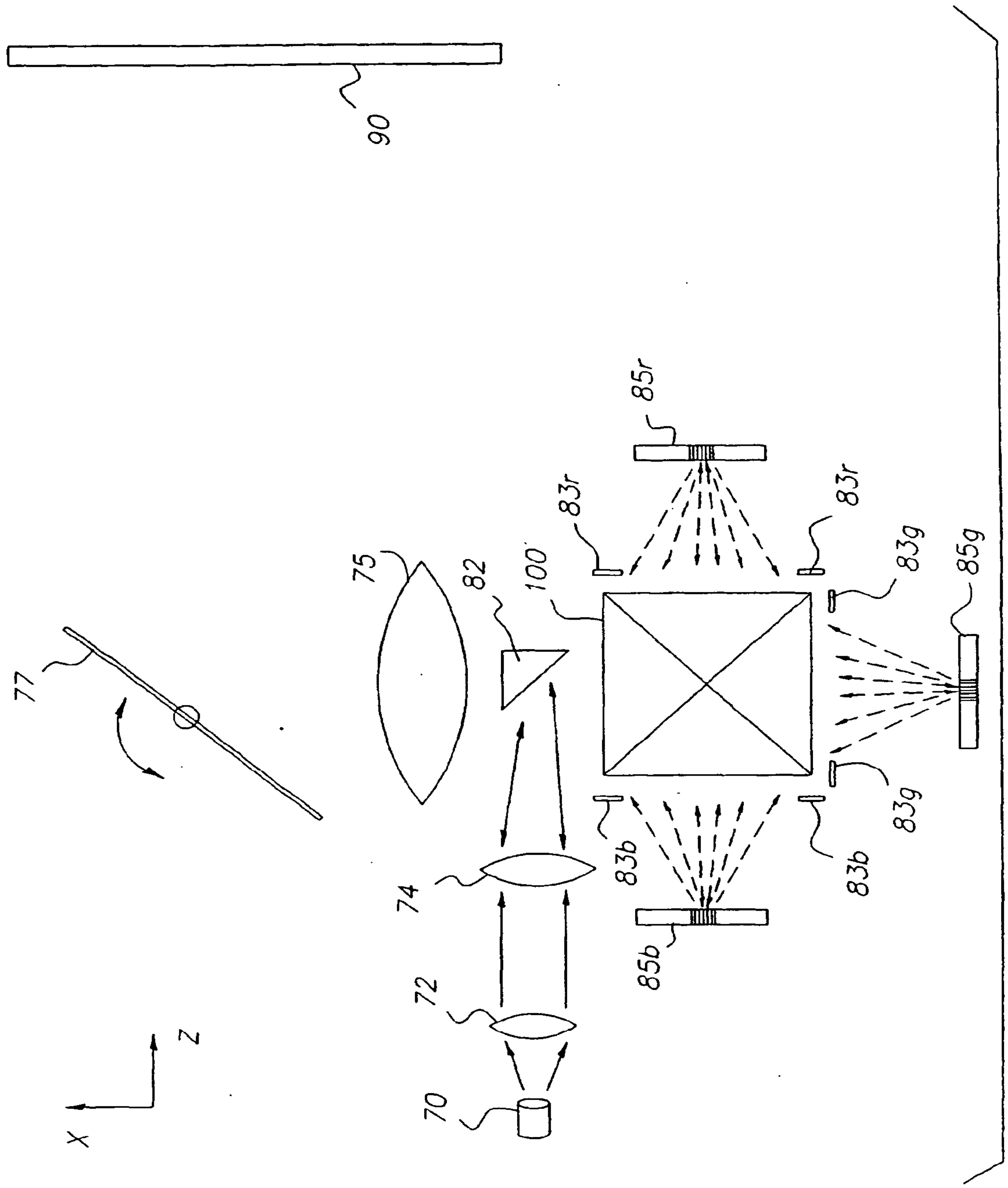
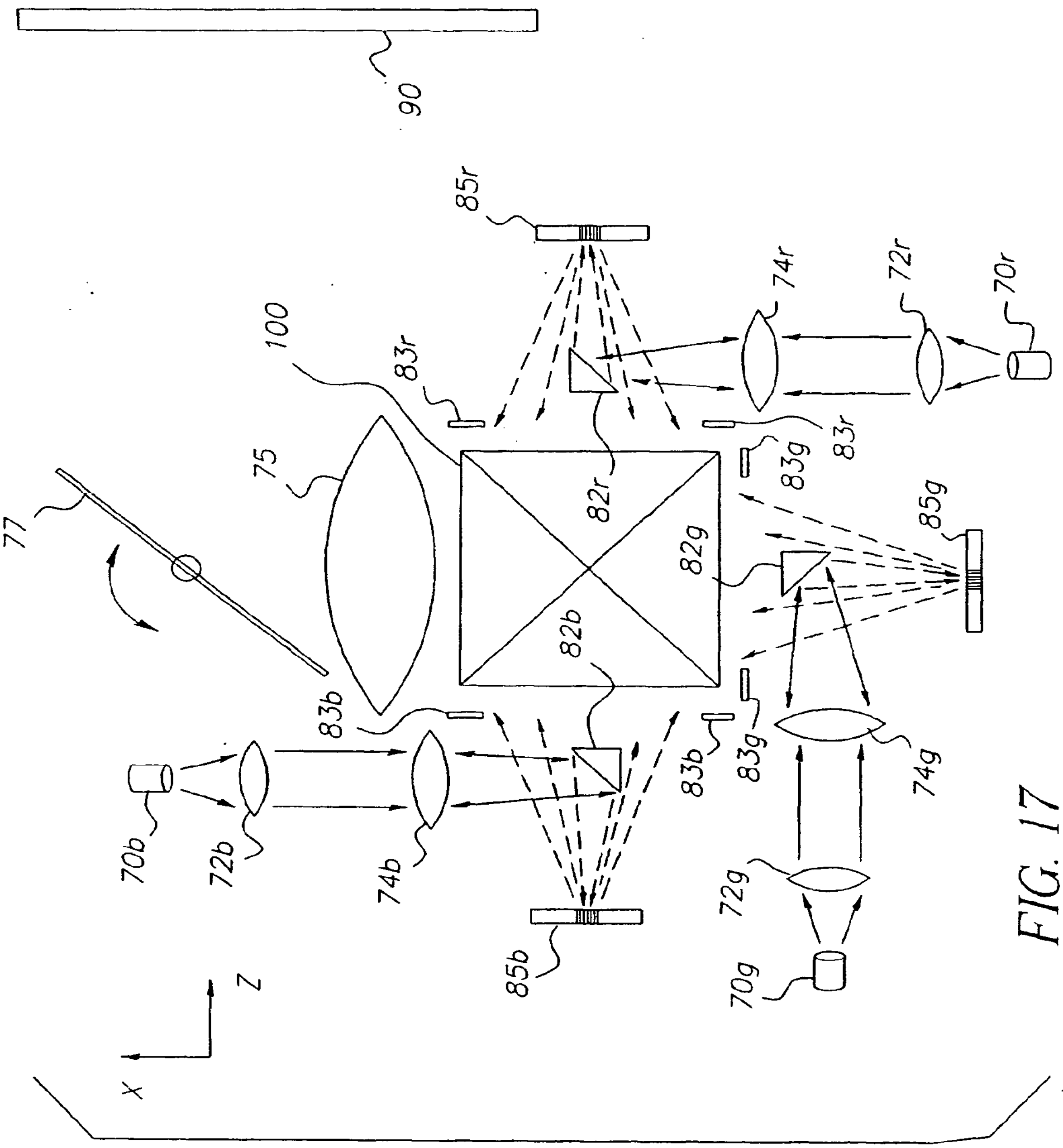


FIG. 16


90
85r
74r
72r
70r
100
83r
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75
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82r
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70b
72b
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72g
85b
70g
Z
X

FIG. 17

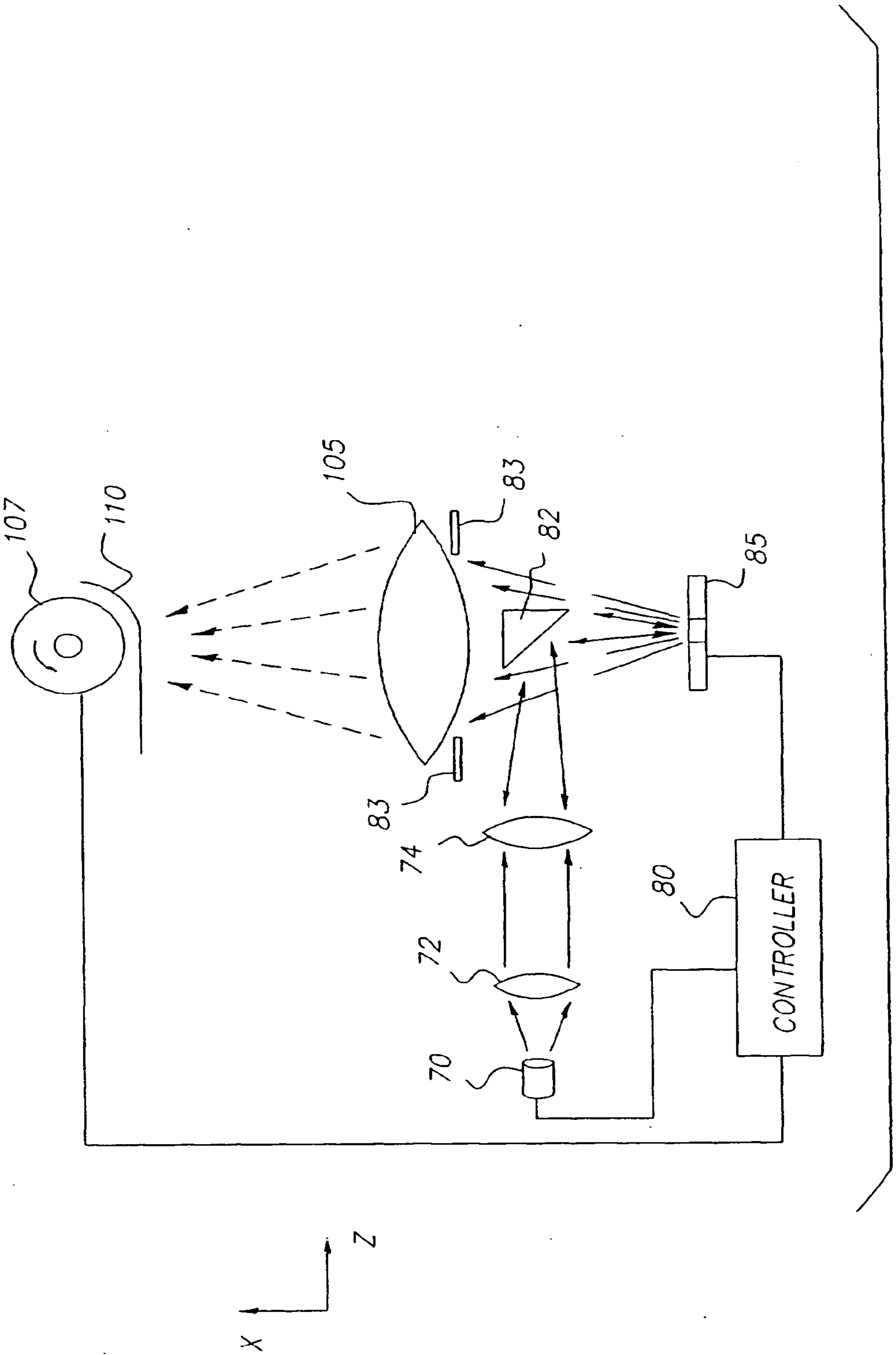

FIG. 18

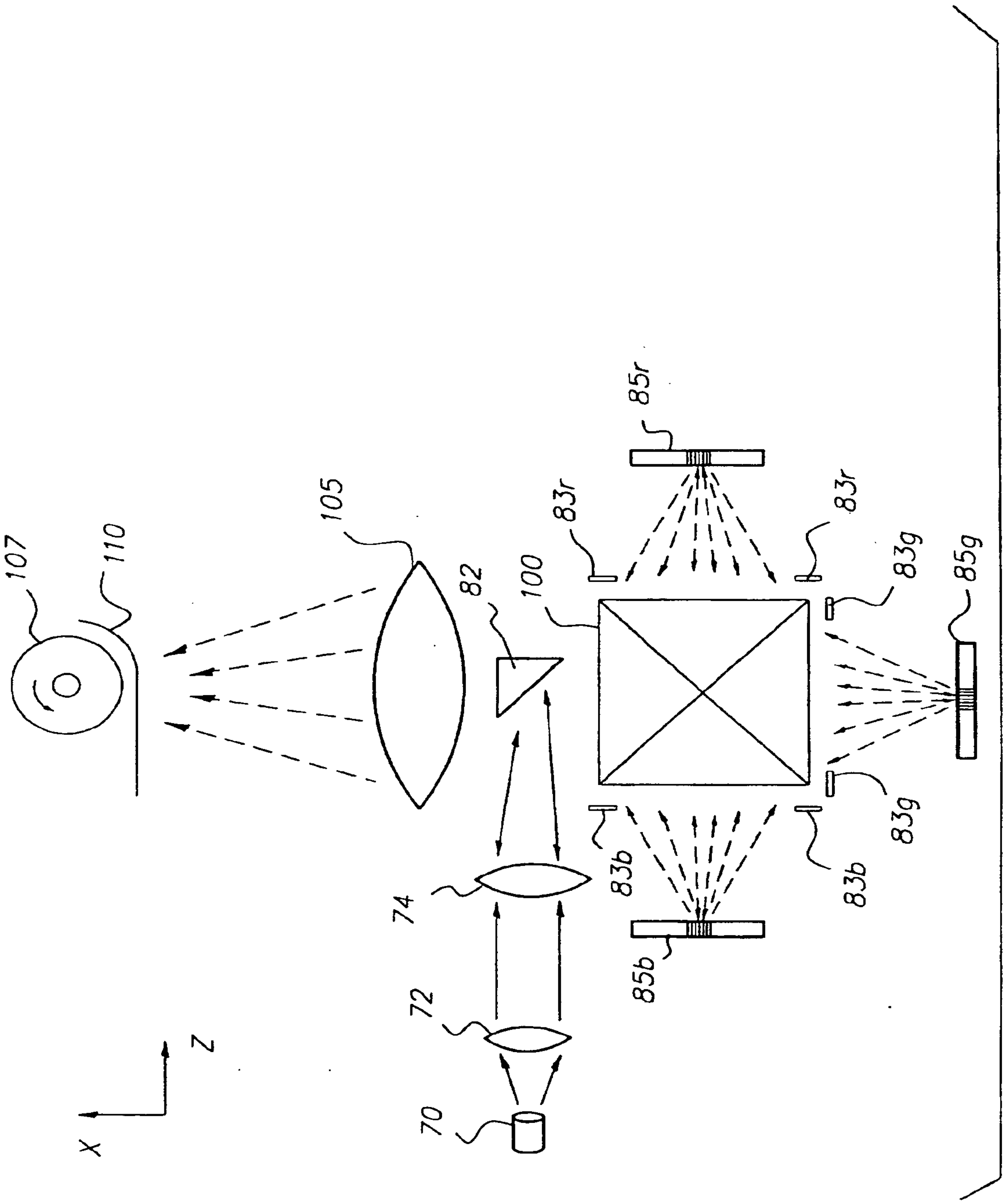

FIG. 19

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 193 525 A3

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03.12.2003 Bulletin 2003/49

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03.04.2002 Bulletin 2002/14

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(22) Date of filing: **19.09.2001**

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Designated Extension States:
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Rochester, New York 14650 (US)

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  Rochester, New York 14650-2201 (US)

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(54) **Electromechanical grating display system with spatially separated light beams**

(57) A display system, that includes a light source for providing illumination; a linear array of electromechanical grating devices of at least two individually operable devices receiving the illumination wherein a grating period is oriented at a predetermined angle with respect to an axis of the linear array wherein the angle is large enough to separate diffracted light beams prior to a lens system for projecting light onto a screen; an obstructing element for blocking a discrete number of diffracted light beams from reaching the screen; a scanning element for moving non-obstructed diffracted light beams on the screen; and a controller for providing a data stream to the individually operable devices.

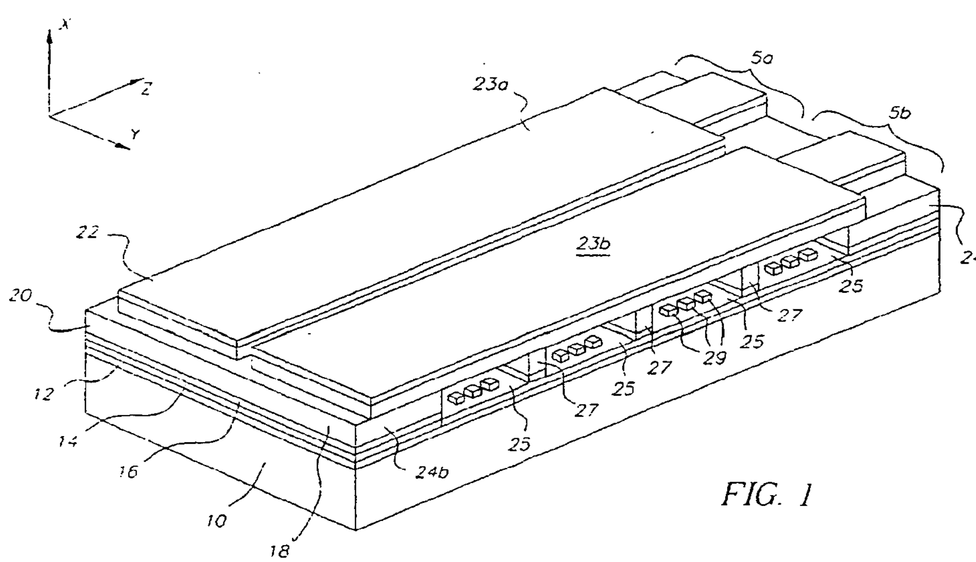

FIG. 1

EP 1 193 525 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 20 3551

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	WO 98 41893 A (SILICON LIGHT MACHINES INC) 24 September 1998 (1998-09-24) * page 9, line 12 - page 12, line 22 * * page 13, line 9 - line 14 * * page 13, line 25 - page 14, line 23 * * figures 4,5,7-11,14 * ---	1-6,9-25	G02B26/08 G02B5/18 G02B26/10 G02B26/02 B81B3/00
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X	WO 99 23520 A (MANHART PAUL K ;SILICON LIGHT MACHINES INC (US)) 14 May 1999 (1999-05-14) * page 15, line 17 - page 16, line 18 * * figures 12,12A,12B * ---	1-8,18	
Y	AMM D T ET AL: "INVITED PAPER: GRATING LIGHT VALVETM TECHNOLOGY: UPDATE AND NOVEL APPLICATIONS" 1998 SID INTERNATIONAL SYMPOSIUM DIGEST OF TECHNICAL PAPERS. ANAHEIM, CA, MAY 17 - 22, 1998, SID INTERNATIONAL SYMPOSIUM DIGEST OF TECHNICAL PAPERS, SANTA ANA, CA: SID, US, vol. 29, 1998, pages 29-32, XP000956146 ISSN: 0098-966X * page 30 - page 31 * ---	1-11,15, 16, 18-21,24	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H04N G02B B81B
Y	BLOOM, D.M.: "The Grating light valve: revolutionizing display technology" SPIE PROCEEDINGS, vol. 3013, February 1997 (1997-02), pages 165-171, XP009018300 * page 166 - page 170 * -----	1-11,15, 16, 18-21,24	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	10 October 2003	von Hentig, R

CATEGORY OF CITED DOCUMENTS

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EPO FORM 1503 03.82 (P04C01)

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10-10-2003

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